EXHIBIT I

Data-Over-Cable Service Interface Specifications Technical Reports

DOCSIS 3.1 Profile Management Application Technical Report

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1 SCOPE

1.1 Introduction and Purpose

CableLabs' DOCSIS 3.1 specifications introduced features that leverage the OFDM-based PHY layer, including variable bit loading, the ability to define multiple modulation profiles on downstream and upstream channels. Other DOCSIS features that need to be supported are upstream probes to check the quality of the upstream OFDMA signal, MAC Management messages to check the quality of a DS and test out profiles in use, etc. There are also extensive additions to important operational items like proactive network maintenance (PNM).

The configuration, initiation logic and compute processing needed to optimize some of these functions (e.g., Downstream (DS) Profile setup, Upstream IUC creation, or Load Balancing of CMs) are not defined in the DOCSIS 3.1 MAC and PHY specifications. This allows such functionality to be moved out of a CMTS and implemented as an "application" running outside the CCAP. Here the idea is to move the profile creation process as an application external to the CMTS. This application can communicate with the CCAP to gather the needed information, process the data, and make intelligent decisions to set up the CCAP as needed.

To realize this idea, the basic steps involve defining the data models and the selection of a protocol to convey the information used by a Profile Management Application (PMA) back and forth. The data models are essentially the information needed by the PMA to gather the needed data elements and performance data, make decisions based on that data, create updated or test profiles that are then instantiated on the channel and then inform the CCAP what DOCSIS 3.1 modems should be assigned to a given set of profiles. The protocol to convey the data and commands must be chosen well, so that every application or a controller which talks to the device on behalf of the applications can communicate easily with the devices.

To leverage the new OFDM/A PHY to its maximum benefit, different subcarriers use different modulation orders. Optimizing the downstream/upstream profiles allows a downstream/upstream channel to be able to operate with lower Signal-to-Noise Ratio (SNR) margin, potentially allowing a channel to operate at an overall higher throughput. The logic to achieve this can be external to a CCAP and enable innovation. For a cable operator, it allows uniform operation of such algorithms across different CCAP platforms.

1.2 Goals

The primary goals of this document are to define the architecture needed to enable a Profile Management Application (PMA), define the needed interfaces, define the information and data models enabling configuration of a DOCSISv3.1 CCAP by a PMA, and define the protocol for information exchange between the PMA and the CCAP. The PMA information model defines the data parameters needed by the profile management application and where to obtain those pieces of data. It also defines the interface between the PMA application and the CMTS. The same data could also be obtained from an external data collection server (e.g., PNM data collection). The protocol defined for PMA information exchange includes the operations needed, such as obtaining MER data and obtaining channel configuration. The second part of the protocol also then allows for setting the profiles on the CCAP for a CM. Typically a profile is created for a group of CMs, and assigned to each CM individually. The goal is to develop the needed APIs and RESTful interfaces as needed by a software developer.

2 INFORMATIVE REFERENCES

This technical report uses the following informative references. References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific. For a non-specific reference, the latest version applies.

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[PMA YANG] CableLabs PMA YANG module, http://mibs.cablelabs.com/YANG/DOCSIS/

[PNM MIB] DOCS-PNM-MIB, http://mibs.cablelabs.com/MIBs/DOCSIS/

[R-UEPI] Remote Upstream External PHY Interface Specification, CM-SP-R-UEPI-I08-171220, December 20, 2017, Cable Television Laboratories, Inc.

[RFC 4546] IETF RFC 4546, Radio Frequency (RF) Interface Management Information Base for Data over Cable Service Interface Specifications (DOCSIS) 2.0 Compliant RF Interfaces, June 2006.

[RFC 6020] IETF RFC 6020, YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF), October 2015.

[RFC 6241] IETF RFC 6241, Network Configuration Protocol (NETCONF), October 2015.

[RESTCONF] IETF RFC 8040, RESTCONF Protocol, January 2017.

2.1 Reference Acquisition

- Cable Television Laboratories, Inc., 858 Coal Creek Circle, Louisville, CO 80027;
  Phone +1-303-661-9100; Fax +1-303-661-9199; http://www.cablelabs.com
- Internet Engineering Task Force (IETF) Secretariat, 46000 Center Oak Plaza, Sterling, VA 20166, Phone +1-571-434-3500, Fax +1-571-434-3535, http://www.ietf.org

3 TERMS AND DEFINITIONS

This document uses the following terms:

Profile Management Application	An external software implementation which manages creation and assignment of profiles/IUCs on a DOCSISv3.1 OFDM/OFDMA channel on a CMTS.
Cable Modem	A modulator-demodulator at subscriber locations intended for use in conveying data communications on a cable television system.
Cable Modem Termination System	Cable modem termination system, located at the cable television system head-end or distribution hub, which provides complementary functionality to the cable modems to enable data connectivity to a wide-area network
Downstream Profile	A downstream profile for an OFDM channel will define the modulation order (i.e., bit loading) on each carrier. In order to account for varying downstream plant conditions across different devices, multiple downstream profiles can be defined, where each profile can be tuned to account for specific plant conditions.
Upstream Profile/IUC	An upstream IUC/profile for an OFDMA channel will define the modulation order (i.e., bit loading) on each minislot and the minislot pilot pattern. In order to account for varying upstream plant conditions across different devices, multiple upstream IUCs can be defined, where each IUC can be tuned to account for specific plant conditions.
Profile A (Downstream)	Profile A denotes the common profile that all CMs can receive and decode. A modem uses Profile A when it first initializes. Each OFDM channel has its own unique set of profiles, including a unique Profile A.
IUC 13 (Upstream)	It is intended that the Burst Descriptor associated with Data Profile IUC 13 is configured as a robust OFDMA profile usable by any DOCSIS 3.1 CM served by that upstream channel. Data Profile IUC 13 is used for all OFDMA data grants to modems which have not completed registration.

4 ABBREVIATIONS AND ACRONYMS

This document uses the following abbreviations:

CCAP	Converged Cable Access Platform
CM	Cable Modem
CMTS	Cable Modem Termination System
CRUD	Create, Read, Update, Delete
DBC	Dynamic Bonding Change
DPD	Downstream Profile Descriptor
DS	Downstream
FDX	Full Duplex DOCSIS
FEC	Forward Error Correction
HFC	Hybrid Fiber-Coaxial
IUC	Interval Usage Codes
MER	Modulation Error Ratio
MMM	MAC Management Message
NACM	NETCONF access control model
NCP	Next Codeword Pointer
NMS	Network Management System
OCD	OFDM Channel Descriptor
OFDM	Orthogonal Frequency Division Multiplexing
OPT	OFDM Profile Test
OUDP	OFDM Upstream Data Profile
PHY	Physical Layer
PLC	PHY Link Channel
PMA	Profile Management Application
PNM	Proactive Network Maintenance
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
REST	Representational State Transfer
RKS	Record Keeping Server
RPC	Remote Procedure Call
SDN	Software Defined Networking
SNR	Signal to Noise Ratio
TAFDM	Time and Frequency Division Multiplexing
TLS	Transport Layer Security
US	Upstream
UCD	Upstream Channel Descriptor
XML	Extensible Markup Language

5 DOCSIS 3.1 PROFILE MANAGEMENT APPLICATION

5.1 Introduction

With the inception of DOCSIS 3.1, the inclusion of OFDM downstream and OFDMA upstream channel types and a high degree of flexibility in using different modulation profiles with variable bit loading, it has become important to define a methodology that enables MSOs to maximize the bandwidth capacity in the HFC. Inspired by SDN Architecture and central to the methodology, a Profile Management Application (PMA) external to the CMTS has been envisioned that takes advantage of network components like the SDN controller and Proactive Network Management (PNM) servers to serve this network optimization function.

In the methodology, the PMA application will be able to identify operational CMTSs with OFDM and OFMDA channels, gather parameters of operating channels, query CMs, CMTS, and PNM servers for data, craft a modulation profile with bit loading that best suits the SNR signal strength at each of the subcarriers within a channel for any one modem, for a group of modems, or for all modems on that channel in case of multicast traffic, and apply modulation profiles to CMs and CMTSs. When the PMA is able to direct the CMTS and CMs to transmit with optimized modulation profiles, data will be transmitted at lower modulation order where SNR margins are lower and higher modulation order where SNR is high rather than transmitting on the entire channel with a single compromised modulation order, allowing for greater total throughput while still maintaining the fidelity of transmitted data.

While the CMTS has historically included DOCSIS-related features like load balancing and modulation profile management, the PMA function is not an intrinsic part of the DOCSIS MAC and PHY layers and can be implemented as an external "application" running outside the CMTS. An external PMA will exchange messages with CMTSs for monitoring, creating, modifying, and assigning modulation profiles. By deploying the PMA application external to any one CMTS, the operator will be able to deploy one PMA application solution across different CMTS platforms and achieve uniform operation of bit loading optimization algorithms. Additionally, the operator will free the PMA from the limited upgrade cycles of CMTS platforms and free the CMTS from the storage and computation requirements of the PMA application. Also, the PMA application can take advantage of external systems such as SDN controllers and PNM data lakes.

This document defines a methodology and associated data model, YANG schemas, and procedures, with which the PMA interacts with CMTSs, CMs, and other network elements to monitor, create, modify and then assign specific profiles to specific DOCSIS 3.1 CMs and fulfill the network optimization function.

5.2 Problem Description

5.2.1 Background

DOCSIS 3.1 introduced the concept of modulation profiles or bit loading characteristics for OFDM/A channels. A modulation profile is a list of modulation orders or bit loading configurations, defined for each subcarrier within an OFDM channel, or for each minislot in a OFDMA channel. A CMTS can define multiple modulation profiles/IUCs for use on a channel, where the profiles differ in the modulation orders assigned to each subcarrier or minislot. A CMTS can assign different downstream and upstream modulation profiles for different groups of CMs.

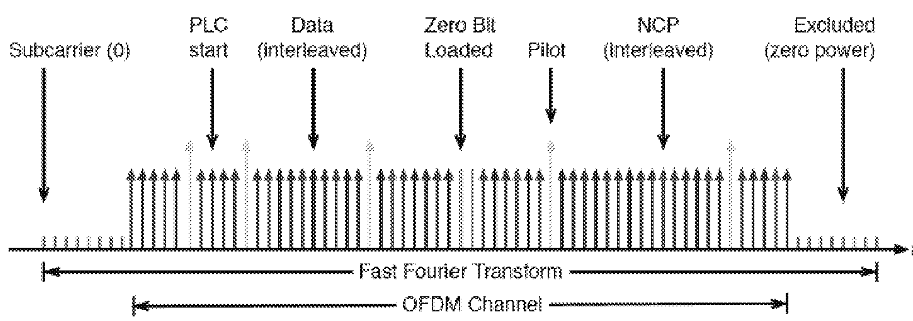


Figure 1 - DOCSIS 3.1 Downstream OFDM Channel

5.2.2 Problem Statement and Goals

Determining the best modulation profile to use on a channel is difficult, given the number of CMs and the differences in signal quality that they experience. The Profile Management Application (PMA) is designed to help operators determine what the best modulation profiles are for each channel, given the channel characteristics seen by each CM on the network. The focus here is first on the optimization of downstream modulation profiles. The second area of focus is on the optimization of upstream profiles. The optimization of downstream profiles targeted at multicast traffic and the associated CMTS and CM steering to these profiles will be considered at a later time. This Technical Report addresses the methods used by a PMA to optimize downstream OFDM profiles as well as upstream OFDMA data-IUC/profiles. This report mainly defines the interfaces through which a PMA can communicate with a CMTS, it does not define the features/implementation or algorithms with a PMA.

The goal of changing profiles is mainly to:

- Increase throughput per CM
- Maximize network capacity by optimizing the bit loading characteristics of every subcarrier in the channel
- Minimize codeword errors which lead to data loss and sub-optimal throughput

The tasks an external PMA performs for both downstream and upstream profiles are as follows:

1. Create a set of optimized modulation profiles for use on a downstream OFDM or upstream OFDMA channel by selecting the best modulation order for each subcarrier based on the channel quality measured at the CMs using the channel profile test. (For all CMs)
2. For a new CM joining the network and periodically for all active CMs, find the best fit among existing modulation profiles and recommend modulation profile usage. (Per CM)
3. Create backup profiles or downgrade a CM based on errors on a certain profile. For example, based on CM performance and SNR margin, provide a better modulation profile for a CM. (Per CM)

The application make suggestions for the above three steps, but it is the CMTS's responsibility to actually apply the changes on the DOCSIS network. The PMA could also be responsible for determining how and when to roll out profile changes, in accordance with MSO policy, but ultimate control remains with the CMTS. In the future, the possibility that the PMA will be responsible for and maintain control of how all the profiles are actively managed is envisioned.

An additional use case to consider is how to determine CMTS profiles to CM population mapping to optimize network capacity.

Full Duplex (FDX) operations introduced into DOCSISv3.1 specifications may affect how profiles are created and will need further investigation; FDX related analysis is deferred to a later time.

5.2.3 High Level Architecture

The following network entities are depicted in the high-level architecture shown in Figure 2 below.

- **Profile Mangement Application (PMA):** Responsible for gathering the data it needs to make profile decisions. It interacts with the CMTS through the SDN controller to initiate modulation profile tests, provide new or optimized modulation profiles, and provide suggestions or commands to use these modulation profiles.
- **SDN Controller:** Mediation/Network Control layer between the applications and the DOCSIS network devices (CMTSs and CMs). Responsible for exposing the profile information from the CMTS/CMs and the profile actions available to the PMA. Also responsible for implementing the communitcation protocols to configure the DOCSIS devices and receive information from the network.
- **CMTS:** Responsible for assigning CMs to use a given modulation profile based either on internal logic or commands originating from the PMA. Source of data for the PMA on network conditions, current configuration, and outcomes of modulation profile testing.
- **CMs:** Use the modulation profile defined and assigned by the CMTS. Act as a source of channel quality data for the PMA.

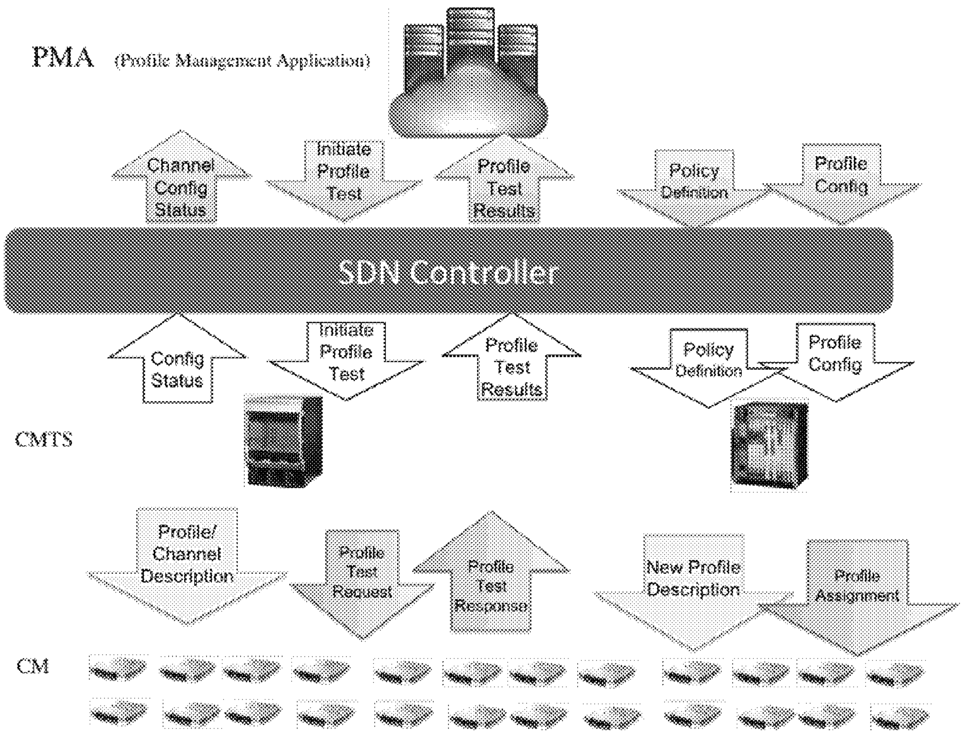


Figure 2 - PMA Architecture w SDN Controller

At a high level, the PMA makes requests of the CMTS to get information from the CMTS, which in turn sends out MAC Management Messages (MMMs) to the CMs to collect the needed information and send it back to the PMA. The PMA also makes recommendations on the profiles to the CMTS, which the CMTS configures CMs to use at an appropriate time.

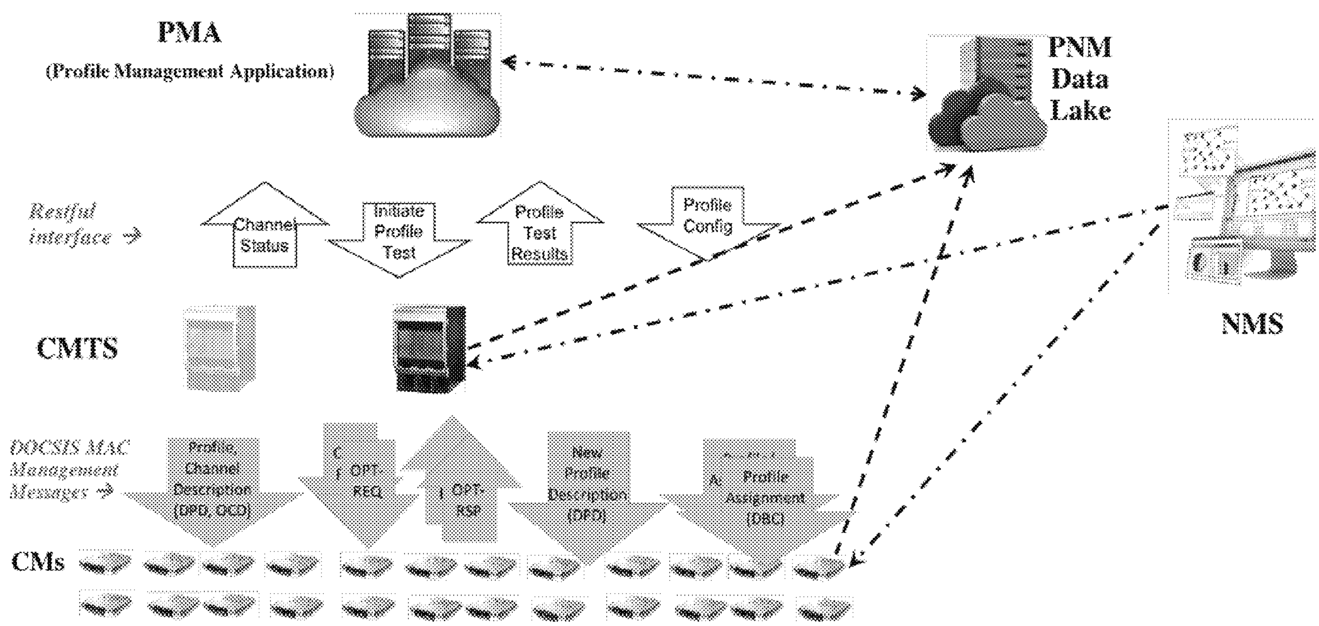


Figure 3 - Alternate PMA Architecture w PNM Data File Lake

An alternate PMA architecture is depicted in the high-level architecture shown in Figure 3. This architecture essentially does not need an SDN controller and the PMA is in direct communication with the CMTS(s).

The PMA architecture can take two approaches to obtain data from the CMs/CMTS: a RESTful/Message-based approach, or an SNMP/Poll/File TFTP approach.

They are described further in the rest of this technical report, the following sections explain how the PMA gets data and communicates with CMTS.

5.2.4 Areas of Focus

The primary areas of focus in developing the PMA are:

- Define PMA actions, that is all the operations needed by the PMA, ultimately to determine the set of modulation profiles that provides the best overall throughput on a channel.
- Information needed by the PMA to analyze channel conditions across the CMs and perform its functions. This includes the definition of the PMA data model in YANG.

The secondary areas of focus are:

- How to get the needed information
- How to effect the changes from PMA on a CMTS
- How to monitor the effect of changes on a CMTS

5.2.5 PMA and Remote PHY

Remote PHY (R-PHY), described in [MHAv2], is a CableLabs specification which defines how to divide CMTS/CCAP functions into two distinct components. The first component is the CCAP Core and the second component is the Remote PHY Device (RPD). In R-PHY architecture, the CCAP Core assumes all responsibilities of a CMTS in a PMA-CMTS interaction. The PMA does not communicate directly with RPDs. For these reasons, the PMA and the interfaces outlined in this Technical Report are not impacted by the Remote PHY architecture.

6 PROFILE MANAGEMENT APPLICATION (PMA) USE CASES

The current assumption for the PMA is a "pull" model, where the PMA has to explicitly query the CMTS or the CMs (or ask the SDN controller to make the query) in order to get the information it needs.

A "push" model might be better. In other words, the CMTS is expected to inform the PMA (or tell the SDN controller which tells the PMA) whenever something changes, e.g., when a channel comes up or goes down, when CMs arrive or leave, when CM statistics are updated, when some sort of high error rate condition is flagged, and so forth. This may prove to be easier on the CMTS. With the pull model, the PMA must constantly query the CMTS to find out if anything has changed, and the CMTS has to keep responding to the same queries repeatedly, even if everything is the same. In contrast, the push model means the CMTS mostly sends out information only when something has changed.

6.1 Case 1: New Channel Startup

The new channel startup case (e.g., on initial deployment) is when the CMTS has been configured with a new Downstream OFDM or Upstream OFDMA channel, but has not been configured with any profiles or only has been configured with a single, non-optimized profile. This could also be when the allocated spectrum is changing or when channel parameters have been changed. The MSO is initializing an OFDM/OFDMA channel on the CMTS and slowly adds DOCSIS 3.1 CMs to the channel over time.

- The PMA learns of the channel (pull model) or CMTS informs the PMA of a new channel being created (push model).
- PMA requests information from CMTS:
  - Requests detailed channel (OCD/UCD) parameters (including configuration about excluded bands) adjacent spectrum usage, and topology information.
  - Requests list of profiles currently active on the channel and CMs assigned to each Downstream (DS) and Upstream (US) channel; there may be none, so no further information needs to be requested.
- The PMA may get other information from places other than the CMTS, including
  - Previous history for this plant segment/frequency range from DOCSIS 3.0 channels/CMs that have used it or from an earlier DOCSIS 3.1 channel.
  - PNM metrics such as spectrum captures gathered from other devices using other frequencies on the plant.
- The PMA can assign to the CMTS a list of profiles to be used as a starting point for the new channel:
  - If there are CMs on the channel, profile assignments to CMs are sent.

6.2 Case 2: Profile Optimization

After completion of Case 1, the CMTS distributes DS Profile Descriptors (DPDs)/ US IUCs and CMs begin to use the channel that has been assigned at registration or via DBC messages. The CMTS assigns each CM one (or more) profiles on its own. The PMA is not in the CM initialization/startup path; the PMA can only operate on registered modems and modems that are registering only get channel assignments and profile information from REG-RSP or post registration via DBC. At this point, data can be gathered from and about the devices actually using the channel. After some period, it would be desirable to have the current set of profiles analyzed to see if the profiles currently configured for the OFDM/OFDMA channel can/should be optimized to better match the conditions affecting devices actually present.

There are two ways to work this under the pull model, as described below.

6.2.1 CMTS Initiated

The CMTS may initiate profile optimization because (a) an operator manually instructs the CMTS to do so, or (b) the CMTS has some sort of internal metrics that trigger a request for profiles to be optimized. For example, a certain

time period has elapsed, a certain number of new CMs have joined and/or old CMs have left, relative utilization of profiles has become unbalanced past a certain point (e.g., some profiles largely unused), and so forth.

The PMA can play a role here by analyzing the available data for the channel and then creating new sets of profiles/IUCs based on that data, that the CMTS can then use to assign to modems. This use case allows the PMA to create new profiles/IUCs for the channel, and leave it to the operator and the CMTS to implement those changes rather than in the PMA initiated case where the PMA performs the step of actually assigning individual modems a new set of profiles/IUCs that are defined for a channel.

In this CMTS-initiated case, the PMA may create the profiles and then tell the operator what CMs can benefit from those profiles or the CMTS can “reshuffle” the CMs per the description above.

6.2.2 PMA Initiated

The advantage of the PMA initiating profile optimization is that the CMTS would not have to include any sort of internal metrics to trigger a request. Instead, the PMA would monitor items such as those described in Section 6.2.1 and decide when optimization is in order. Put another way, the PMA's job would be not only to calculate optimized profiles, but also to determine when optimization should be considered and then carry out the assigning of CMs to use the optimized profiles. This moves the burden of the active profile management tasks to the PMA rather than the CMTS.

6.2.3 Steps to Optimize the Profile(s)

For option 1, CMTS Initiated:

- The CMTS sends a request to the PMA for optimization of profiles for the channel.

For option 2, PMA Initiated, the above step is skipped. Instead, the PMA decides it is going to do an optimization without any explicit message to that effect. Everything else is the same.

- Using the pull model, the PMA requests the information it needs to ensure that its data is current:
    - The PMA requests OCD (OFDM Channel Descriptor) or UCD (Upstream Channel Descriptor) parameters; the CMTS responds with this information.
    - The PMA requests list of profiles/IUCs and CMs assigned to each; the CMTS responds with this information.
    - The PMA requests DPD (Downstream Profile Descriptor) information for each DS profile or IUC information for each US IUC; the CMTS responds with this information.
    - The PMA requests OPT (OFDM Profile Test) information from each active CM; this could be requested from the CMTS. The PMA requests OUDP (OFDM Upstream Data Profile) test information from the CMTS, for each CM. Alternatively the RxMER values can be obtained from a PNM data server, to which CMs and CMTS upload their PNM files (via TFTP).
    - The PMA may want other CM performance-related information; e.g., FEC statistics, packet counts (total/errored), etc. These metrics can be obtained from the DOCSIS interface statistics from the CM and the CMTS.
    - The PMA may want profile (or IUC) traffic statistics (e.g., transmitted byte counts, FEC uncorrectables). These might come from a CMTS or from a PNM data server, to which CMs and CMTS upload their PNM files (via TFTP).

After gathering all this information, the PMA comes up with a list of profiles (or IUCs) and a list of CMs to be assigned to each profile/IUC.

Now the PMA is expected to manage the process of changing over to the new profiles. Most likely, it (and the operator) will want some amount of profile testing done prior to switching over to the new profiles. This step is a benefit of the PMA-initiated model.

So the PMA may perform these steps:

- If all the profiles on a CMTS are already in use, the PMA may have to free up some profiles so that they can be configured for testing. The PMA will tell the CMTS to move CMs off of a few profiles or if the CMTS has not room to create a new profile, the PMA application should flag this and not continue with the optimizations.
- The PMA sends the CMTS a list of profile assignments for certain CMs to move all CMs away from profiles that are to be decommissioned.
- Once all CMs are moved, the PMA tells the CMTS to delete the now-unused profile(s). In DOCSIS, there is not a formal way to delete a profile. However, once no CMs are using a specific profile, a CMTS can stop sending DPDs for the 'deleted' profile.
- Or, if the PMA is going to start using these profiles for something else right away, it could just tell the CMTS to do a DPD change.
- Either way, the PMA tells the CMTS to add a new profile or to change a currently unused profile to be one of the new profiles it wants to test.
- The PMA tells CMTS to perform OPT testing on the new profile with a CM or CMs that it expects will be able to use the new profile.
- If the testing is successful, the PMA tells CMTS to assign the profile to the CM and then goes on to the next CM.

Once all desired CMs have been moved to the first new profile, the PMA can repeat this process for subsequent profiles, until all CMs have been moved.

If at any point problems are encountered, the PMA can alter its plan as needed. For example, if a particular CM does not perform well enough in the profile (OPT) tests (too many FEC errors, for example), the PMA may decide that it will instead move that CM to a lower or different new profile. This could even be part of the strategy; run profile tests on a profile that is "optimistic" for the CM in question, and see if it works.

Recall that profile tests (OPTs) can typically take 3~10 seconds to run. Switching to a new set of profiles affecting many CMs/flows should be expected to take multiple tens of minutes or more.

6.3 Case 3: "Fallback" Use Case

In the Fallback use case, a CM has been operating for some time on a channel (may be a short time or a long time) but begins experiencing errors. Here it is expected that the CMTS is the "first line of defense". When the condition is detected (e.g., using CM-STATUS), the CMTS may/should take action to move the CM to a different profile. Involving the PMA might take too long; it is better to quickly move the CM to a profile that gives it some (less efficient) service than to let it continue to lose packets.

If the PMA has listed "backup" profiles in the profile-to-CM assignments, the CMTS could first move the CM to the "backup" profile; otherwise, it could move the CM to profile A, or to which other profile it thinks will work. Now this concept of backup profiles is not defined in DOCSIS, but a PMA could use this concept as it manages variable plant conditions.

After this has been done, the CMTS might ask the PMA to intervene:

- The CMTS sends a request to the PMA for a new profile for a specific CM.
- Under the "pull" model, the PMA now requests the latest information about the channel:
  - OCD
  - List of profiles and CMs assigned
  - DPDs for profiles

Then the PMA requests latest information about the CM.

The PMA also collects any other information such as traffic statistics from NMS, PNM information, etc. It may also want to examine its history of previous profile assignments for the CM.

The PMA processes information and determines a recommendation. This could involve leaving the CM where it is, choosing a different profile for the CM from among those currently configured, or setting up a new profile and moving the CM and possibly other CMs over to it.

Whatever the PMA decides, it uses the same set of commands described in Section 6.2.3 to accomplish its goals.

6.4 Push versus Pull Approaches

A "push" approach makes sense for some scenarios but not all. Specifically, anything reflecting channel properties or CM state should be pushed. This includes OCD and DPD information, profile/CM assignments, and CM join/leave. These things cannot change without the CMTS knowing, so there is no point in having the PMA ask repeatedly for this information. It may ask at wide intervals (hourly, for example) to ensure nothing was missed, but it should not have to poll every 10 seconds to stay up-to-date.

A "pull" approach probably makes more sense for measurement results such as OPT-REQ/OPT-RSP. The PMA decides when it needs new information or when the information it has previously stored is sufficiently recent. This is not to say the CMTS could not push these things if available. For example, if it does an OPT test on a CM for its own reasons, it might make sense for the CMTS to share the results with the PMA. However, for these items, the PMA cannot assume that nothing has changed since the last set of results, so it's fair to expect it to ask for what it needs when it needs it.

A downside of this is that with a "pull" model, the PMA must frequently query the CMTS (say every 1 minute or 15 minutes or up to once an hour) for a list of profiles and assigned CMs. This is an example of a case where a "push" model would be lighter-weight; whenever a new CM joins, the CMTS sends information about it. If no new CMs have joined, it does not have to constantly answer queries about it.

With either model, the PMA would probably want traffic statistics at frequent intervals (say tenths of seconds to a minute) and it would want to keep a history of these statistics. However, this is probably already being monitored by an NMS, so the PMA most likely could get it from there.

7 DOWNSTREAM PMA

7.1 Downstream PMA Problem Statement

DOCSISv3.1 technology introduces OFDM in the downstream direction. This allows each subcarrier within the channel to be provisioned with multiple modulation orders. This usage of multiple modulation orders across the OFDM Channel is known as a profile.

The main question is how best to create a set of profiles for all the modems on the OFDM Channel, such that it can maximize the total network capacity and throughput per CM. To make this happen, consider what are the main data interfaces that are needed to communicate between the PMA and the CMTS

7.1.1 Downstream PMA Solution

The idea is to allow an external application to read the state of the network (i.e., RxMER data of the CMs), either from the CMTS or from a file server where CM's upload their PNM data. The PMA processes this data, processes its algorithms, and calculates the best set of profiles for the set of CMs. The PMA then signals these profiles to the CMTS. The PMA then, depending on the model used/supported, sends the new profile definitions and the profile assignments of CMs, to the CMTS.

Next Codeword Pointer (NCP) Profile Definition is out of scope for a PMA. NCPs may be modulated using QPSK, 16-QAM or 64-QAM and this modulation is signaled by the CMTS to the CM in the PLC messages. The choice of NCP modulation order is determined by an MSO.

7.2 Downstream PMA System Operation

The Profile Management Application, CCAP, and CMs work together to perform the following workflow or sequence of actions to achieve the goals described previously. The sections that follow identify and describe the steps in the downstream PMA workflow.

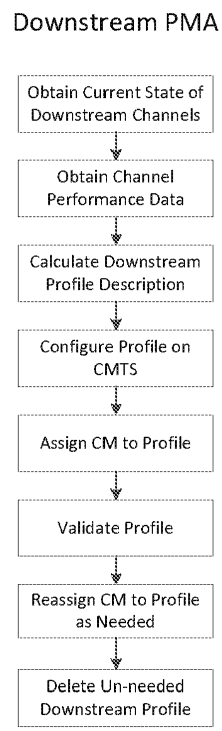


Figure 4 - Downstream PMA Workflow

7.2.1 Obtain Downstream Channel Current State

The PMA obtains the current state of downstream OFDM channels in use, to establish a baseline for channel measurements and possible changes to be made to profile assignments based on channel measurements.

- List of OFDM channels in use: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:ds-rf-port/pma:ds-ofdm-channel endpoint of [PMA YANG] to obtain a list of all OFDM channels configured in each CCAP.
- List of profiles for each OFDM channel: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:ds-rf-port/pma:ds-ofdm-channel/pma:ds-ofdm-profile endpoint of [PMA YANG] module to obtain a list of all profiles configured for each OFDM channel.
- List of CMs per OFDM channel: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:ds-rf-port/pma:ds-ofdm-channel/pma:channel-cm-list endpoint of [PMA YANG] module to obtain a list of CMs by MAC address assigned to each channel in the CCAP and identify CMs that are assigned to each OFDM channel.
- List of profiles in use by each CM for each channel: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:ds-rf-port/pma:ds-ofdm-channel/pma:ds-ofdm-profile/pma:profile-cm-list endpoint of [PMA YANG] module to obtain a list of downstream profiles per channel for each CM assigned to an OFDM channel.

7.2.2 Run Downstream Tests on Existing Profiles

The PMA initiates execution of tests in the CCAP to measure the quality of an OFDM channel to determine what modifications, if any, are needed for the profiles used for that channel. To accomplish this, the PMA calls the /pma:run-ds-opt-test RPC of [PMA YANG] to trigger the CMTS to generate an OPT Request (OPT-REQ) message with all bits set in the requested statistics and test fields as per [MULPIv3.1].

The CM returns to the CMTS in the OPT Response (OPT-RSP) a list of channel statistics including Receive MER (RxMER), SNR margin, codeword statistics, and NCP statistics corresponding to each downstream subcarrier received in the OFDM channel used by the CM. The CMTS returns the channel statistics to the PMA in the /pma:run-ds-opt-test RPC response.

As an alternative to calling the /pma:run-ds-opt-test RPC, the PMA has the option to initiate the OPT-RSP message generation in the CMTS using SNMP by writing to objects in the docsPnmCmtsOptReqTable of the PNM MIB in the CMTS [PNM MIB].

7.2.3 Evaluate Downstream Channel Performance Data and Defines New Profiles

The PMA evaluates the downstream channel statistics (mainly RxMER values per subcarrier from each CM) returned by the CMTS and determines the optimum downstream profile definition for the channel. The PMA profile creation algorithm is vendor proprietary.

7.2.4 Configure Downstream Profile on CMTS

When the PMA creates the profile optimized for the channel, it configures the CMTS with the new profile using the POST method on the CCAP using the CCAP YANG /pma:pma-ccap/pma:slot/pma:ds-rf-port/pma:ds-ofdm-channel/pma:ds-ofdm-profile endpoint.

7.2.5 Assign Downstream Profile to Cable Modem

The PMA calls an RPC in the PMA YANG with the CM MAC address, channel ID, and index of the new profile to assign the new downstream profile to the CM.

The two assignment options are:

1) Assign a single profile to a group of CMs: /pma:assign-single-profile-to-cm-list
2) Assign a set of profiles to a single CM: /pma:assign-list-of-profiles-to-cm

7.2.6 Test New Downstream Profile

To validate the new downstream profile, the PMA again calls the /pma:run-ds-opt-test RPC passing the CM's MAC address and profile index, receives the channel statistics, and compares the performance results with the results from the initial downstream channel performance evaluation. Based on the results of the comparison, the PMA may leave the profile configuration unchanged or delete the profile from the set of configured profiles.

One could also use an /pma:run-ds-opt-test RPC to initiate an OPT message to test out a profile on a CM prior to assigning it. The modem uses the profileId in the OPT message as a test profile, obtains the corresponding DPD information, does the tests and then passes back the results.

The PMA could also direct the CMTS to use the profiles it tailored for a set of CMs and periodically test the CM performance on a particular profile over time.

7.2.7 Delete a Downstream Profile

If the PMA determines a need to remove a downstream profile from the CMTS, it uses the DELETE method [RESTCONF] on the CCAP with the /pma:pma-ccap/pma:slot/pma:ds-rf-port/pma:ds-ofdm-channel/pma:ds-ofdm-profile/pma:profile-index endpoint.

7.3 Downstream PMA Data Elements and Actions

A Profile Management Application (PMA) needs to exchange information with the CCAP device and potentially obtain information from the CMs. This includes gathering information about OFDM channel parameters and performance, as well as providing CCAP devices with OFDM channel-modulation profile configuration decisions based on analyzing the gathered data. A PMA does this continuously to adapt to the changing conditions of OFDM channels and the CMs that use them.

There is no need to do modulation profile management for the DOCSIS 3.1 Physical Link Channel (PLC). The need for NCP modulation profile management is also very unlikely. The focus of profile management is for the regular data subcarriers.

This section defines the message content across the PMA and CMTS interface for configuration and management of downstream OFDM channel profiles.

The type of information that is used by Downstream PMA may fall into one of the following categories:

- OFDM channel parameters and statistics: This includes the OFDM channel configuration parameters and error statistics from both the CMTS and the CMs.
- DOCSIS network topology and subscriber information: Information such as the fiber node layout, the CM association with service groups, and CM time offset (to indicate the CM distance from the CMTS) could be useful for the PMA, as well as other SDN applications.
- Topographical and other cable plant information: Topographical information that is used by PNM.

For the last two categories, whether such messages should be defined within PMA or in the wider scope of PNM will be defined in the future.

7.3.1 Downstream PMA Information Model

Many of the data attributes required by the PMA to identify and analyze DOCSIS OFDM channels so it can calculate the required profiles and communicate them to the CMTS are defined in DOCSIS 3.1 OSSI specifications. Currently-defined DOCSIS information models required by the PMA are referenced in the subsections below. Information models required by the PMA that are not already defined by DOCSIS specifications are also described below.

7.3.1.1 Downstream OFDM Channel Information

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the DsOfdmChannelStatus object that provides identifiers, state, configuration settings, and channel utilization for each OFDM channel.

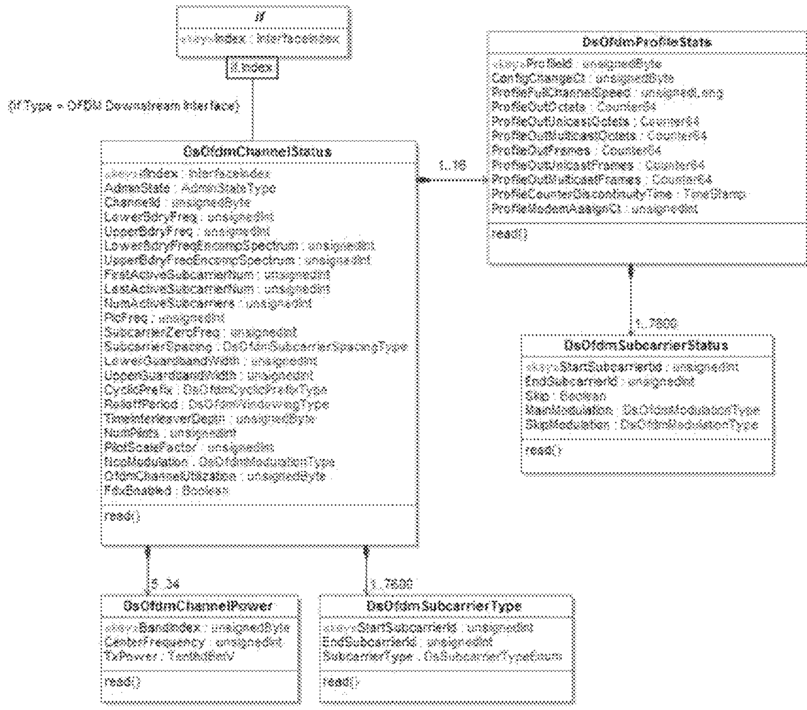


Figure 5 - DsOfdmChannelStatus Object

7.3.1.1.1 Downstream OFDM Channel Profiles Information

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the DsOfdmProfileCfg object that provides identification, modulation order (bit loading), and subcarrier configuration settings for each OFDM channel profile. A copy of the DsOfdmProfileCfg object is shown in Figure 6.

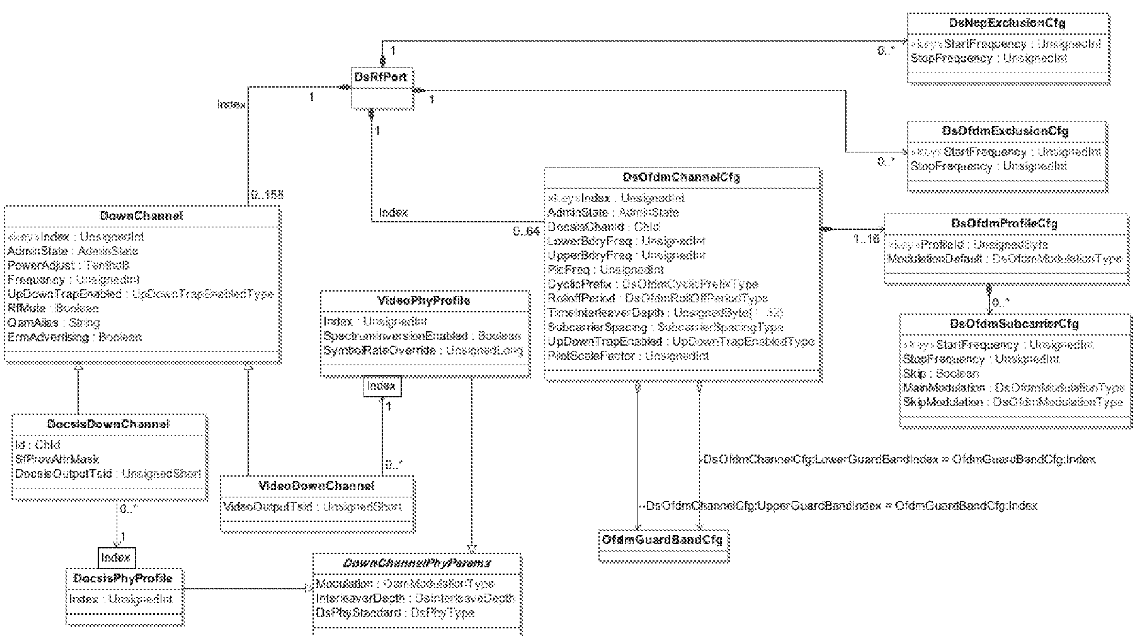


Figure 6 - Downstream DOCSIS Configuration Objects

7.3.1.2 List of CMs Using OFDM Channels

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the CmtsCmRegStatus object (shown in Figure 7) that provides identification, partial service and channel conditions, and configuration information including the Transmit Channel Set and Receive Channel Set for any specified registered CM.

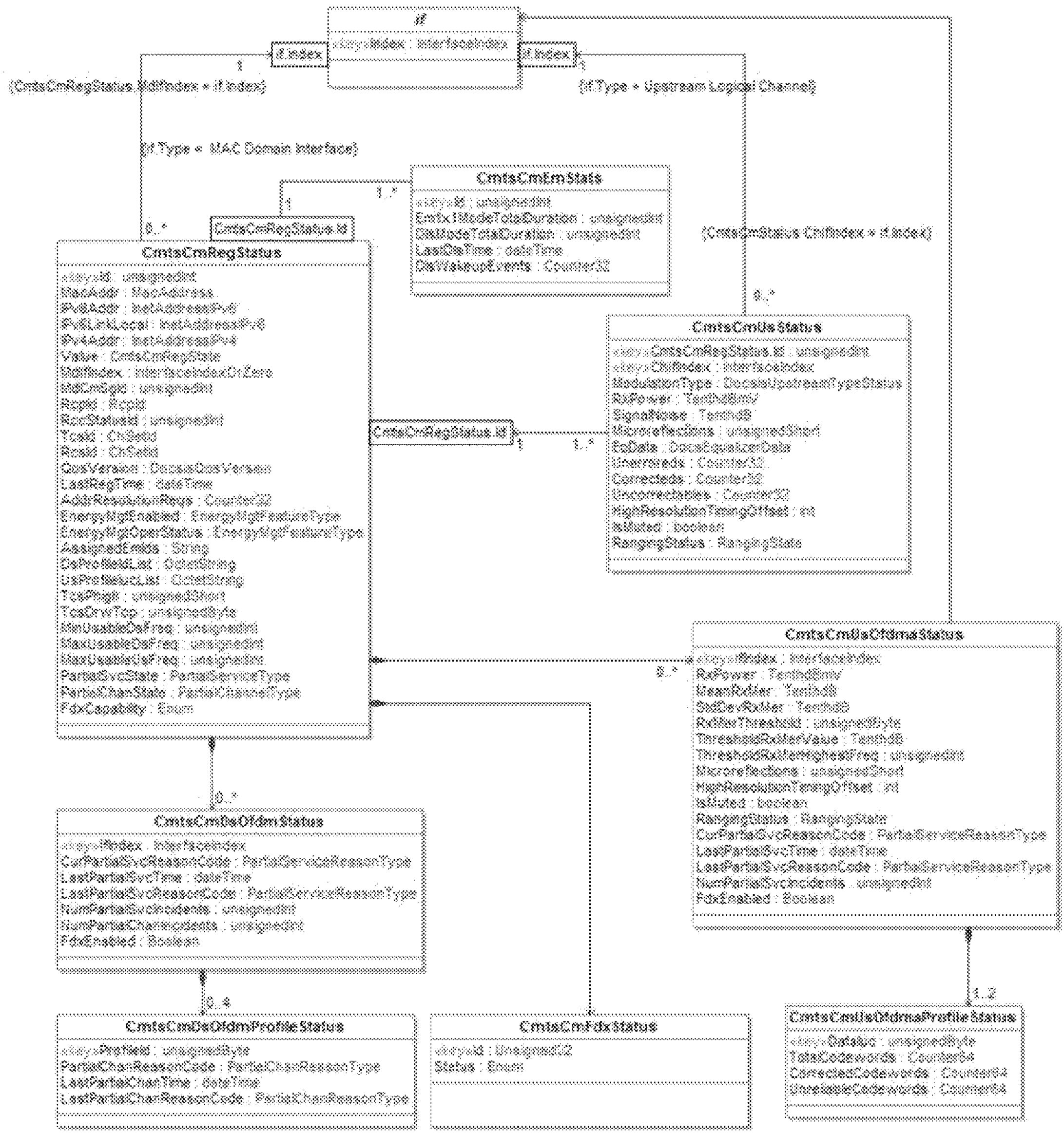


Figure 7 - CMTS CM Status Information Model

7.3.1.3 Profiles in Use by CMs for Each Channel

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the CmtsCmRegStatus, CmtsCmDsOfdmStatus, and CmtsCmDsOfdmProfileStatus objects that provide per CM per channel profile information. These objects are shown in Figure 7.

7.3.1.4 Initiate Channel Conditions Test for a Profile

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the OptReq object (shown in Figure 8) that provides the means for the management interface to initiate one or more of the following tests:

- Receive MER statistics per subcarrier
- Receive MER per subcarrier threshold comparison for candidate profile
- Signal to Noise Ratio (SNR) margin for candidate profile
- Codeword statistics for candidate profile
- Codeword threshold comparison for candidate profile
- Next Codeword Pointer (NCP) field statistics
- NCP cyclic redundancy check (CRC) threshold comparison

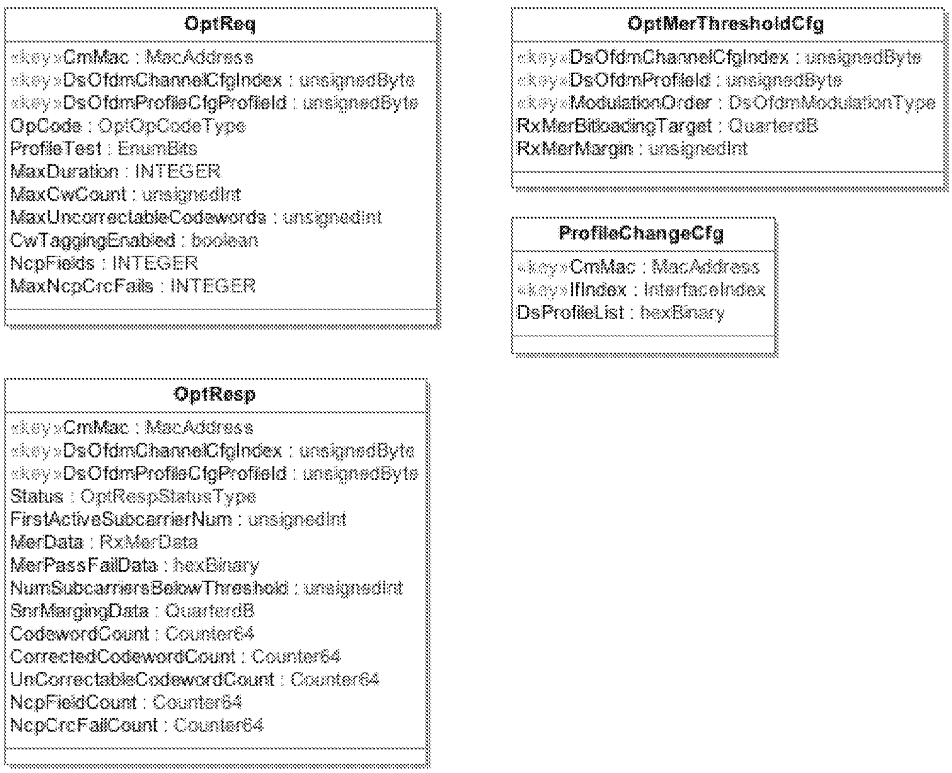


Figure 8 - CCAP OPT PNM Information Model

7.3.1.5 Instantiate a New Profile on CCAP

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for descriptions of DsOfdmChannelCfg, DsOfdmProfileCfg, and DsOfdmSubcarrierCfg objects that provide attributes for defining the modulation per subcarrier and skip vs. continuous subcarrier assignment for each profile. These objects are included in the Downstream DOCSIS Configuration Object information model diagram shown in Figure 6.

7.3.1.6 Assign a Profile to a CM

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the ProfileChangeCfg object that provides the means for the management interface to assigned profiles on a specified registered CM. Figure 8 illustrates the ProfileChangeCfg object UML.

7.3.1.7 Evaluate Target Test Profile

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the OptReq object that provides the means for the management interface to initiate one or more tests for a specified OFDM channel. The OptReq object UML is shown in Figure 8.

7.3.2 Downstream PMA Data Model

The Downstream PMA Information Model is implemented as a set of YANG modules. The PMA YANG modules are listed here: pma.yang , cl-pma-types.yang [PMA YANG]

This PMA YANG module is meant to be an individual YANG Module which can be supported by a CMTS. Alternatively, it could be combined with the DOCSIS 3.1 CCAP YANG Model (ccap.yang [CCAPv3.1 YANG]). A CMTS would implement a RESTCONF (or NETCONF) interface to support this PMA YANG model.

7.3.3 Message Elements and Structure for a PMA-CMTS Interface

This section defines the type of messages and the message content needed for the PMA-CMTS interface. This is a high-level design of the interface. It identifies the kinds of data which need to flow back and forth and the operations which need to be supported for a PMA solution. This section is a generic framework for a PMA-CMTS interface. The actual YANG model was developed based on the requirements from this section.

These messages and the data needed are covered in the YANG data structures, for which the PMA-CMTS interface uses RESTCONF/NETCONF. An alternate implementation could define these as messages which could be carried back and forth using some other protocol (instead of RESTCONF/NETCONF). Table 1 provides a list of messages that are used for downstream channels.

Table 1 - PMA-CMTS Downstream Messages

Message	Description
Downstream OFDM Channel Descriptor	Conveys the configured channel parameters for a downstream DOCSIS 3.1 channel.
Downstream Profile Request	Either a request from the CCAP for a new profile or a request from PMA for the details of an existing profile.
Downstream Profile Descriptor	Provides the configuration details of a modulation profile.
Downstream Profile Test Request (OPT-REQ Test Request)	Request from the PMA for the CCAP to test a specified modulation profile. Request from the PMA for the a test to be run for a channel on a given CM.
Downstream Profile Test Response (OPT-RSP Test Response)	Conveys the results of the test of a modulation profile on a specified CM. Response from the CMTS with results for the a test which was run previously for a channel on a given CM.
CM-to-Profile Assignment Request	Request for a list of CMs that are assigned a specified modulation profile.
CM-to-Profile Assignment Descriptor	Provides a list of CMs that are or are to be associated with a modulation profile.
Profile-to-CM Assignment Request	Request for a list of the profiles that are assigned to a CM.
Profile-to-CM Assignment Descriptor	Provides a list of channels and modulation profiles that are assigned or should be assigned to a CM.

Although a PMA may manage multiple CMTSs, it is assumed that each CMTS can be uniquely identified by its host IP address, which is in each message's header. So the message content defined here is within the context of a single CMTS. This section does not imply that the interface needs to use TLV-based messages. The intent of this section is to tease out the needed information exchange.

7.3.3.1 Downstream OFDM Channel Descriptor

The PMA needs to have the OFDM channel parameters configured on the CMTS. The Downstream OFDM channel descriptor is for OFDM parameters that are common across profiles. This message is from the CMTS to the PMA.

This message closely resembles the OCD message defined in DOCSIS 3.1 MULPI specification (most fields are copied from [MULPIv3.1]).

Table 2 - Downstream OFDM Channel Descriptor Message

Name	Type	Length (bytes)	Value
IfIndex	Integer (Int32)	4	
Config change count	Unsigned Byte	1	
OCD Parameters	OCD parameters same as in the "OFDM Channel with PLC After Interleaving" Table in [MULPIv3.1].		

7.3.3.2 Downstream Profile Request

When sent from the CMTS to the PMA, this message is used by the CMTS to request the PMA to provide a new set of profiles, or the details of a specific profile identified by profile ID, for a downstream OFDM channel.

When sent from the PMA to the CMTS, this message requests the current profiles being used on the CMTS to be sent to the PMA.

An IfIndex of 0 indicates a request for all the profiles and all downstream OFDM channels on a given CMTS. A Profile ID of 0xFE indicates a request for all profiles on the downstream OFDM channel specified by the IfIndex.

Table 3 - Downstream Profile Request Message

Name	Type	Length (bytes)	Value
IfIndex	Integer (Int32)	4	
Profile ID	Unsigned Byte	1	

7.3.3.3 Downstream Profile Descriptor

When sent from the CMTS to the PMA, this message is used to inform the PMA which modulation profile is currently being used on the CMTS.

When sent from the PMA to the CMTS, this message is used to inform the CMTS of the profile computed by the PMA. In this case, the configuration change count is ignored.

Table 4 - Downstream Profile Descriptor Message

Name	Type	Length (bytes)	Value
IfIndex	Integer (Int32)	4	
Profile ID	Unsigned Byte	1	
Configuration change count	Unsigned Byte	1	
Profile attributes	Unsigned Int	2	Bits definitions to indicate if the profile is used for multicast, voice, etc.
Subcarrier Assignment Range/List	Subcarrier assignment TLV as defined in the "Subcarrier Assignment List/Range TLV" Table and the "Subcarrier Assignment Vector TLV" Table in [MULPIv3.1].		

Profile descriptors may be sent from the CMTS to the PMA, or from the PMA to the CMTS, with or without the Downstream Profile Request message.

7.3.3.4 OFDM Downstream Profile Test Request

This message is for the PMA to request that the CMTS send an OPT-REQ message to the specified CMs to test a modulation profile on a channel. A broadcast CM MAC address indicates a request to send the OPT-REQ to all CMs on the OFDM channel. A list of CM MAC addresses indicates a request to send the OPT-REQ to all the CMs in the list. If one of the modems in the list is offline when it is its turn to run the test, the CMTS responds with the appropriate status in the response.

Table 5 - OFDM Downstream Profile Test Request Message

Name	Type	Length (bytes)	Value
CM MAC address list	MacAddress	6 * N	
IfIndex	Integer (Int32)	4	
Profile ID	Unsigned Byte	4	
Op code	Unsigned Byte	1	1 – Start 2 – Abort
Profile Test Encodings	OPT-REQ TLV encodings as specified in the "OPT-RSP TLV Encodings" Table in [MULPIv3.1].		

7.3.3.5 OFDM Downstream Profile Test Response

This message is how the CMTS informs the PMA of the downstream profile test results for a CM. If the request was sent to multiple CMs, one response will be sent for each CM that received the request.

Table 6 - OFDM Downstream Profile Test Response Message

Name	Type	Length (bytes)	Value
CM MAC address	MacAddress	6	
Timestamp (time of day)	Unsigned Int	4	
IfIndex	Integer (Int32)	4	
Profile ID	Unsigned Byte	1	
Status	Unsigned Byte	1	1 - Testing 2 - Profile Already Testing from Another Request 3 - No Free Profile Resource on CM 4 - Max Duration Expired 5 - Aborted 6 - Complete 7 - Profile already assigned to the CM All other values reserved
Profile Test Results Encodings	OPT-RSP TLV encodings as in the "OPT-RSP TLV Encodings" Table in [MULPIv3.1].		

7.3.3.6 DOCSIS 3.1 OFDM Profile Test Information Model

The OFDM Profile Test (OPT) is performed using MAC Management Message (MMM) [MULPIv3.1] to evaluate several different parameters associated with a Downstream OFDM profile.

An OPT measurement is requested by the CMTS through the generation of an OPT-REQ message to the CM required to perform the test. The CM performs the requested OPT measurements using the parameters described in the OPT-REQ message. Upon successful completion of the test, the CM returns the OPT results in the OPT-RSP message.

The OPT message exchange has been designed to support the following:

- Retrieval of the per-subcarrier MER values from the CM, which is a channel level measurement
- Compilation by the modem for codeword statistics including Codeword Counts, Uncorrectable Codeword Counts, and the ability to enable codeword tagging
- Execution of NCP Profile tests, which include the NCP Field Counts and NCP CRC failure counts

The [CCAP-OSSIv3.1] specification has defined an ability to trigger the CMTS to send an OPT request message for a given CM or downstream OFDM channel to provide testing on the current channel or profiles that the PM application wishes to have tested. Table 7 describes the various tests that can be requested and the required attributes that need to be present for each test to be initiated by the CMTS.

Table 7 - OFDM Profile Tests Triggered by CMTS

Profile Test	Test Description	Required Attributes
RxMER Statistics per Subcarrier	Per subcarrier MER regardless of modulation or profile	CmMac, DsOfdmChannelIndex, DsProfileId
RxMER per Subcarrier Threshold Comparison for Candidate Profile	When this test is selected, the CM uses MER target values for each modulationOrder in the candidate Profile referenced in DsProfileId. Target values are configured in the OptMerThresholdCfg with RxMerVsBitloadingTarget	CmMac, DsOfdmChannelIndex, DsProfileId Test requires that one or more instances of OptMerThresholdCfg exist for the referenced CmMac, DsOfdmChannelIndex, DsProfileId
SNR Margin for Candidate Profile	When this test is selected, the CM uses the threshold values in the OptMerThresholdCfg for the specified DsOfdmChannelIndex, DsProfileId, ModulationOrder and the RxMerVsBitloadingTarget from the OptMerThresholdCfg	CmMac, DsOfdmChannelIndex, DsProfileId Test requires that one or more instances of OptMerThresholdCfg exist for the referenced CmMac, DsOfdmChannelIndex, DsProfileId, ModulationOrder and that RxMerMargin is set to a non-zero value.
Codeword Statistics for Candidate Profile	When this test is selected, the CM provides Codeword Statistics for the candidate profile	CmMac, DsOfdmChannelIndex, DsProfileId, MaxDuration, MaxCodewordCount and optionally MaxUncorrectedCw and CwTagging
Codeword Threshold Comparison for Candidate Profile	When this test is selected, the CM provides Codeword Statistics for the candidate profile	CmMac, DsOfdmChannelIndex, DsProfileId, MaxDuration, MaxCodewordCount and optionally MaxUncorrectedCw and CwTagging
NCP Field statistics	When this test is selected, the CM provides NCP Statistics for the candidate profile	CmMac, DsOfdmChannelIndex, DsProfileId, MaxDuration, NcpFieldCount, and optionally MaxNcpCrcFailCount and CwTagging
NCP CRC Threshold Comparison	When this test is selected, the CM provides NCP Statistics for the candidate profile	CmMac, DsOfdmChannelIndex, DsProfileId, MaxDuration, NcpFieldCount, and optionally MaxNcpCrcFailCount and CwTagging

Tests like the RxMER per Subcarrier Threshold Comparison for Candidate Profile and the SNR Margin for Candidate Profile require the CMTS to provide values for the CM to make the evaluations needed in the test. For this, the PMA or operator configures entries for each of the profiles on each of the DS OFDM channels in the *OptMerThresholdCfg* object.

Downstream OFDM profiles are created for each downstream channel. The *DsOfdmProfileCfg* object defined in the [CCAP-OSSIv3.1] specification allows the operator of the PMA to create and manage the profiles associated with a specific DS OFDM channel.

Once an OPT request message has been processed by the CM, the CM returns the requested data in an OPT-Response message. The information is then recorded in the *OptResp* object. This object reflects the structure of the OPT-RSP message defined in [MULPIv3.1].

7.3.3.7 CM-to-Profile Assignment Request

This message is used to request a list of CMs that are assigned to a specific profile. When sent from the PMA to the CMTS, it requests the current CM to profile assignment on the CMTS.

A Profile ID of 0xFE indicates a request for CM-to-profile assignment for all the profiles on the downstream OFDM channel specified by the IfIndex.

Table 8 - CM-to-Profile Assignment Request Message

Name	Type	Length (bytes)	Value
IfIndex	Integer (Int32)	4	
Profile ID	Unsigned Byte	1	

7.3.3.8 CM-to-Profile Assignment Descriptor

This message is used to provide a list of CMs that are assigned to a profile. When sent from the CMTS to the PMA, it describes the current CM to profile assignment used on the CMTS. When sent from the PMA to the CMTS, it describes the suggested CM to profile assignment as recommended by the PMA. The profile change count is used to ensure that the PMA and CMTS are referring to the same profile version. This message may be sent with or without the CM-to-profile assignment request.

Table 9 - CM-to-Profile Assignment Descriptor Message

Name	Type	Length (bytes)	Value
IfIndex	Integer (Int32)	4	
Profile ID	Unsigned Byte	1	
A list of CM MAC address	MacAddress	6 * n	CM MAC address

7.3.3.9 Profile-to-CM Assignment Request

This message is used to request a list of modulation profiles that are assigned to a CM. When sent from the CMTS to the PMA, it requests the PMA to suggest the modulation profile to modem assignment for the CM. When sent from the PMA to the CMTS, it requests the current modulation profile to CM assignment on the CMTS for the specified CM.

Table 10 - Profile-to-CM Assignment Message

Name	Type	Length (bytes)	Value
CM MAC address	MacAddress	6	

7.3.3.10 Profile-to-CM Assignment Descriptor

This message is used to provide a list of downstream OFDM channels and modulation profiles assigned to a CM. When sent from the CMTS to the PMA, it describes the current profile to CM assignment used on the CMTS for that CM. When sent from the PMA to the CMTS, it describes the suggested modulation profiles to CM assignment as computed by the PMA. The profile change count is used to ensure that the PMA and CMTS are referring to the same profile version. The profile attribute is a bit mask used to indicate for what the profile is used. This message may be sent with or without the profile-to-CM assignment request.

Table 11 - Profile-to-CM Assignment Message

Name	Type	Length (bytes)	Value
CM MAC address	MacAddress	6	
A list of (IfIndex, Profile ID, profile change count, profile attributes)	An octet string	(4+1+1+2) * n	

7.3.3.11 CMTS DS Capabilities and PMA Configuration

Additional information may be useful to configure a PMA, for example:

- Constraints on profiles, e.g., the upper limit of the range of bit loading values a CMTS supports.
- The number of profiles that a CMTS supports per OFDM Channel.
- Constraints on the number of modulation order changes supported across one OFDM channel.
- Support for Even/Odd subcarrier bit loading: provides mixed bit loading, i.e., an average of 9.5 or 10.5 bit loading across a set of subcarriers instead of discrete levels of 9 or 10 or 11 bits per symbol. This essentially modifies the MER range to be 1.5 db instead of 3 db.
- Constraints on a CM's bit loading ranges (if any).

Other information can be exchanged at boot time that is not channel-specific, e.g., topology information.

8 UPSTREAM PMA

8.1 Upstream PMA Problem Statement

The management of Upstream OFDMA profiles (also known as Interval Usage Codes (IUC)) can be as complicated or more complicated than the management of the downstream profiles on a given cable plant. DOCSIS 3.1 technology allows for upstream channels to be created in frequency bands that are already occupied with outside carriers (AM and FM radio, aeronautical bands, etc.) as well as TDMA DOCSIS 3.0 channels. These additional considerations have to be accounted for when evaluating the effectiveness of upstream profiles. For upstream profile(IUC)s, the focus is on just the data-IUCs and not on any other IUC definition such as station maintenance and ranging. The goals of the upstream profile management are similar in many respects to the downstream profiles in that they are to:

- Increase throughput per CM
- Maximize network capacity by optimizing the bit loading characteristics of every subcarrier in the channel
- Minimize codeword errors which lead to data loss and sub-optimal throughput

8.1.1 Upstream PMA Solution

The tasks an external PMA performs are as follows:

- Create a set of optimized modulation profiles(IUCs) for use on an upstream OFDMA channel by selecting the best modulation order for each subcarrier and pilot patterns based on the channel quality measured at the CMs using the channel profile test. (For all CMs)
- For a new CM and periodically, find the best fit among existing modulation profiles(IUCs) and recommend modulation profile(IUC) usage. (Per CM)
- Select the pilot pattern for each minislot.
- (Optional/Advanced feature) Determine the appropriate placement of minislots in the upstream channel, accounting for exclusion zones.

As with downstream, the PMA makes suggestions for upstream Profile(IUCs) creation and assignment, but it is the CMTS's responsibility to actually implement the changes on the DOCSIS network.

DOCSIS 3.1 Proactive Network Management tools are one source of information and data gathering methodologies that the PMA application can rely on to gather the data needed to make the complex evaluations of performance that are needed for upstream OFDMA channels. Some new programmatic interfaces may be required to support retrieval of the upstream profile(IUC) performance data as well as the interfaces to help implement the external management of these profiles. As with the downstream management methods provided in this document, the upstream profile management section defines some new and existing data models that aid in performing the data gathering and new profile(IUC) creation on the CMTS.

To satisfy the objectives, the PMA needs an interface to the CMTS to perform the following functions:

- Initiate upstream channel RxMER measurements at the CMTS by commanding the CM to transmit probes
- Initiate OUDP profile testing at the CMTS for each CM
- Retrieve test results from CMTS
- Send profile(IUC) definitions, pilot patterns and CM-to-profile(IUC) assignments to CMTS
- Send recommended minislot placement for the upstream channel to the CMTS. (This would be advanced functionality, as it changes the channel definition itself.)

8.2 Upstream PMA System Operation

The Profile Management Application, CCAP, and CMs work together to perform the following workflow or sequence of actions to achieve the Upstream goals described in Sections 5.2.2. The following subsections identify and describe the steps in the upstream PMA workflow.

8.2.1 Obtain Upstream Channel Current State

The PMA obtains the current state of upstream OFDMA channels in use, as a baseline for channel measurements and possible changes to be made to profile(IUC) assignments based on channel measurements.

- List of OFDMA channels in use: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channelendpoint of [PMA YANG] to obtain a list of all OFDMA channels configured in each CCAP.
- List of profile(IUC)s per OFDMA channel: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channel/pma:us-ofdma-iuc endpoint of [PMA YANG] to obtain a list of all data IUCs configured for each OFDMA channel.
- List of CMs per OFDMA channel: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channel/pma:channel-cm-list of [PMA YANG] to obtain a list of CMs assigned to each upstream OFDMA channel. As an alternative to /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channel/pma:channel-cm-list, a PMA can use SNMP to read docsIfCmtsCmStatusTable of DOCS-IF-MIB [RFC 4546] for the list of CM by MAC address assigned to each channel in the CCAP and identify CM that are assigned to each OFDMA channel.
- List of upstream data IUC in use by each CM for each channel: The PMA uses the GET method on the CCAP /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channel/pma:us-ofdma-iuc/pma:iuc-cm-list endpoint of [PMA YANG] to obtain a list of data IUCs assigned to each CM. As an alternative to /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channel/pma:us-ofdma-iuc/pma:iuc-cm-list, the PMA can use SNMP to read the docsIf31CmtsCmRegStatusUsProfileIucList in the docsIf31CmtsCmRegStatusTable of DOCS-IF31-MIB [DOCS-IF31-MIB] for each CM assigned to an OFDMA channel, to obtain the list of upstream data IUC in use by each CM, for each OFDMA channel.

8.2.2 Run Upstream Tests on Existing Profiles(IUC)

The PMA initiates execution of tests in the CMTS to measure the quality of an OFDMA channel to determine what modifications, if any, are needed for the data IUCs used for that channel. The PMA has the option to initiate the Upstream Receive Modulation Error Ratio (RxMER) per upstream subcarrier (PNM function defined in [PHYv3.1]), trigger an OUDP Test (defined in [MULPIv3.1]), or both.

When the Upstream Receive Modulation Error Ratio (RxMER) Per Subcarrier upstream Proactive Network Maintenance function is configured and initiated, the CCAP returns a list of MER values corresponding to each upstream subcarrier received in the OFDMA channel used by the CM specified by MAC address in the function input attributes. The PMA can configure the location where the CMTS saves the output file.

When the PMA initiates the Trigger OUDP Test, the CCAP returns total FEC codewords, corrected FEC codewords, unreliable FEC codewords, total MAC frames, and MAC CRC failures received during the execution of the test, for the upstream channel used by the CM specified by the MAC address in the function input attributes.

- Run OUDP Test:

  The test is defined in DOCSISv3.1 MULPI. The PMA-CMTS interface is defined in the YANG model. It defines the interface to the CMTS to initiate an RPC to CM to initiate OUDP test. It is similar in function to the OPT for the Downstream, but now for the upstream OFDMA channel. The idea here is to define an upstream test profile(IUC) and ask a CM to use it and test it. The CM generates test data and the CMTS receiver evaluates received DOCSIS frames and generates codeword and CW error counters. The CMTS finally returns data (see YANG model) from the OUDP test. To accomplish this, the PMA calls the /pma:run-us-rxmer-test RPC of [PMA YANG] to trigger the CMTS

- Run "Upstream Probes and RxMER Measurements" test

  The PMA-CMTS interface to initiate probe test is defined in the YANG model. This is implemented as an RPC for initiating a request for RxMER via Upstream Probe (via P-MAP). The CMTS receives the RPC, generates P-MAP with RxMER bit set. The CM generates probes and the CMTS receiver evaluates MER (on the probes) and computes RxMER values. The CMTS finally returns data (see YANG model) for the RxMER test. To accomplish this, the PMA calls the /pma:run-us-oudp RPC of [PMA YANG] to trigger the CMTS.

8.2.3 Evaluate US Channel Performance Data and Define New Data IUCs

The PMA uses many types of data which help determine the optimal profiles(IUCs) and assign groups of CMs to them. Inputs used by the PMA are as follows: Profile(IUC) statistics, upstream Codeword FEC statistics, US RxMER per subcarrier (obtained by PNM mechanisms or from test which uses probes) of the channel. In addition, upstream Equalizer Coefficients could also be useful.

The PMA evaluates the data received from the CMTS, and creates profiles(IUCs). The algorithms to evaluate the US plant data is proprietary to the developer of the Profile Management Application.

8.2.4 Configure Upstream Data IUC on CMTS

When the PMA creates the upstream data IUC optimized for the channel, it configures the CMTS with the new IUC using the POST method on the CCAP using /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channel/pma:us-ofdma-iuc endpoint of [PMA YANG].

Pilot patterns are used for synchronization (Pattern 1 is the most efficient, whereas pattern 4 is more robust.) The US Channel response can be used to decide pilot patterns. When configuring the bit loading for minislots within the IUCs, the PMA also configures the Pilot pattern.

8.2.5 Assign US Data IUC to Set of Modems

The PMA calls an RPC in the [PMA YANG] with the CM MAC address, channel index, and index of the new data IUC to assign the new upstream data IUC to the CM.

The two options for these are

1) Assign a single profile(IUC) to a group of CMs: /pma:assign-singleiuc-to-cm-list
2) Assign a set of profiles(IUC) to a single CM: /pma:assign-list-of-iucs-to-cm

8.2.6 Test New IUC: Probe and/or OUDP

After configuring the CMTS with a new upstream data IUC, the PMA has the option to call the /pma:run-us-rxmer-test or /pma:run-us-oudp RPC on [PMA YANG] passing the CM's MAC address, channel index, data IUC identifier, and number of test packets to repeat the upstream channel test and verify the performance of the new data IUC. When the PMA initiates the run-oudp RPC, it receives the channel statistics, and compares the performance results with the results from the initial upstream channel performance evaluation. Based on the results of the comparison, the PMA may leave the profile(IUC) configuration unchanged or delete the profile(IUC) from the set of configured profile(IUC)s.

The PMA could also direct the CMTS to use the profiles(IUC) it tailored for a set of CMs and periodically test the CM performance on a particular profile over time.

8.2.7 Delete IUC

If the PMA determines a need to remove an upstream data IUC from the CMTS, it uses the DELETE method on the CCAP for the /pma:pma-ccap/pma:slot/pma:us-rf-port/pma:us-ofdma-channel/pma:us-ofdma-iuc on the [PMA YANG].

8.3 Upstream PMA Data Elements and Actions

8.3.1 Upstream PMA Information Model

Many of the data attributes required by the PMA to identify and analyze DOCSIS OFDMA channels so it can calculate the required Upstream Data Profiles (UDP) and communicate them to the CMTS are defined in DOCSIS 3.1 OSSI specifications. Currently defined DOCSIS information models required by PMA are referenced below. Information models required by PMA that are not already defined by DOCSIS specifications are also described below.

8.3.1.1 Upstream OFDMA Channel Information

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the UsOfdmaChannelStatus object that provides identifiers, state, configuration settings, and channel utilization for each OFDMA channel.

The CMTS needs to provide the PMA with complete information detailing channel's configuration, including the all information conveyed in UCD messages to the CMs. The details of channel's configuration conveyed via UCD can be found in [MULPIv3.1]. These include the following channel and burst configuration attributes: Center Frequency of Subcarrier 0, Subcarrier Spacing, Subcarrier Exclusion Band, Unused Subcarrier Specification, Symbols in OFDMA frame, DOCSIS 3.1 Burst Descriptors for all active IUCs, and minislot arrangement. The CMTS needs to provide the PMA with the operational state of the channel. The PMA can retrieve this information from the CMTS via a DOCS-IF31-MIB defined in [CCAP-OSSIv3.1].

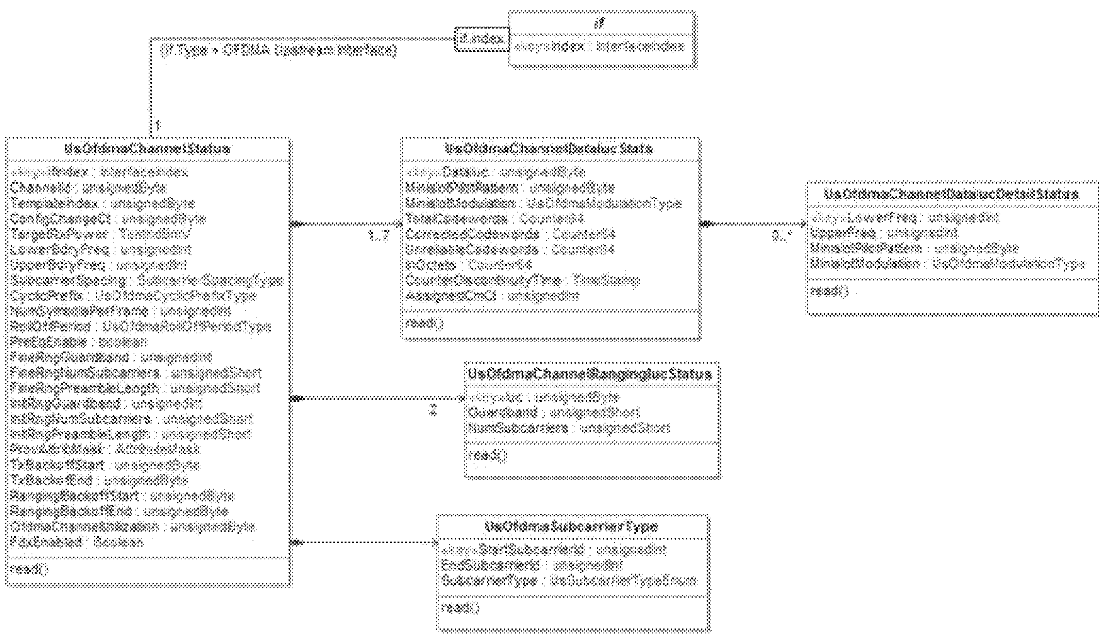


Figure 9 - Upstream OFDMA Status Objects UML Model [CCAP-OSSIv3.1]

8.3.1.2 Upstream OFDMA Channel IUC Data Profile Information

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the UsOfdmaChannelStatus, UsOfdmaChannelDataIucStats, and UsOfdmaChannelDataIucDetailStatus objects that provides identification and minislot modulation (bit loading) for each OFDMA channel profile(IUC). Refer to the UML diagram in Figure 9 (above).

8.3.1.3 List of CMs Using OFDMA Channels

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the CmtsCmRegStatus object that provides identification, partial service and channel condition, and configuration information including the Transmit Channel Set and Receive Channel Set for any specified registered CM.

Refer to Figure 7 CMTS CM Status Information Model.

8.3.1.4 Data IUC in Use by CMs for Each Channel

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the CmtsCmRegStatus which provides the list of upstream data IUC (UsProfileIucList) in use by each registered CM. A copy of this object is shown in Figure 7 CMTS CM Status Information Model.

8.3.1.5 Initiate Channel Conditions Test for a Data IUC

Section 8.2.2 references two channel conditions test functions defined by DOCSIS 3.1 specifications. The information models defined to support these channel conditions tests are described below in Section 8.3.1.5.1 and Section 8.3.1.5.2.

8.3.1.5.1 Initiate Receive MER per Upstream Subcarrier Test

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the UsOfdmaRxMerPerSubcarrier information model defining the attributes for configuring and initiating the Receive MER per Upstream Subcarrier test. A copy of the class diagram is provided in Figure 10.

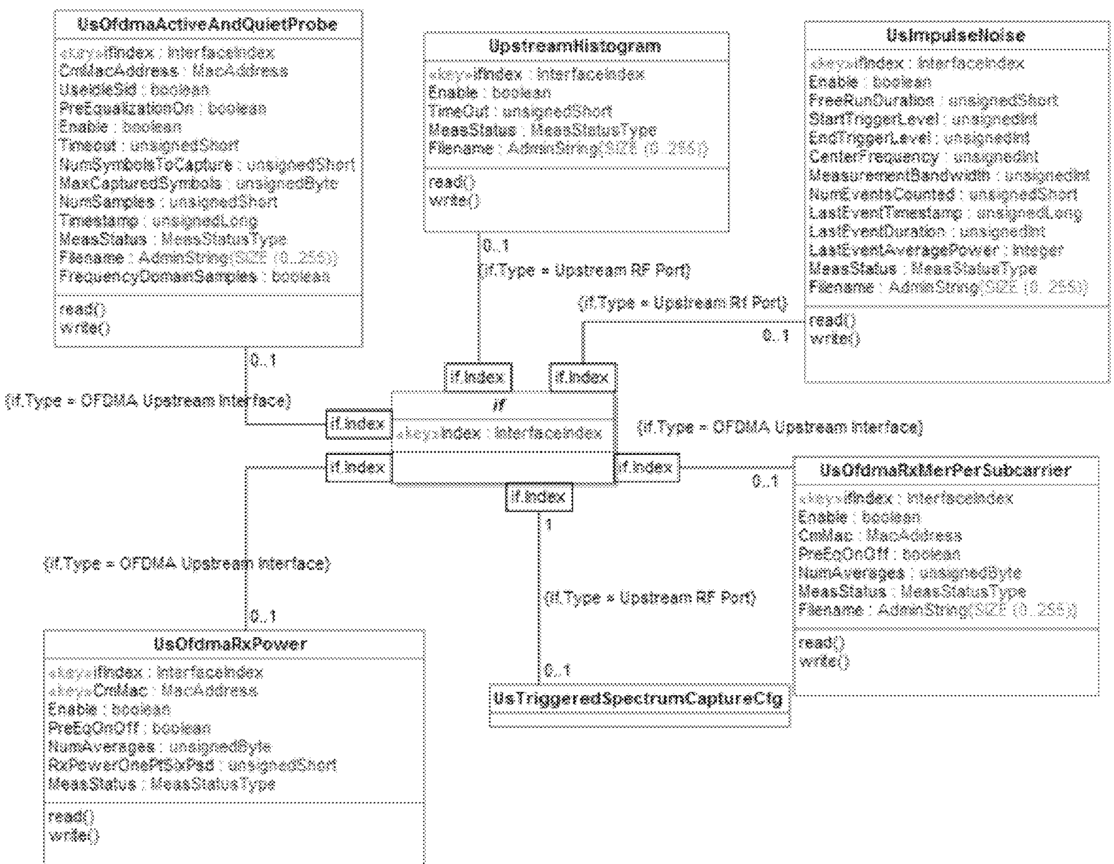


Figure 10 - UsOfdmaRxMerPerSubcarrier UML Model [CCAP-OSSIv3.1]

8.3.1.5.2 Run Data OUDP Bursts Test

The [MULPIv3.1] specification defines Upstream Data Profile Testing Bursts for measuring upstream data IUC performance. The data profile(IUC) testing bursts provide another method for PMA to evaluate channel conditions for defining upstream data IUCs to optimize use of upstream OFDMA channels.

The OUDP Test Request model illustrates the object and attributes required to initiate the Run Data OUDP Bursts test. The OUDP Test Response model illustrates the object and the attributes returned by the CMTS in response to the OUDP Test Request. Table 12 identifies the attributes required for initiation of the Data OUDP Bursts Test. Table 13 identifies the attributes to be returned by the CMTS after the Data OUDP Bursts Test is executed.

Table 12 - OudpBurstTestReq Object

Attribute Name	Type	Access	Type Constraints	Units	Default Value
CmMac	MacAddress	Key			
UsOfdmaChannelCfgIndex	UnsignedByte	Key			
UsOfdmaDataIucId	UnsignedByte	Key	0..4 | 255		
NumberOfEthernetPackets	Unsigned64	R/W			

Table 13 - OudpBurstTestRsp Object

Attribute Name	Type	Access	Type Constraints	Units	Default Value
CmMac	MacAddress	Key			
UsOfdmaChannelCfgIndex	UnsignedByte	Key			
UsOfdmaDataIucId	UnsignedByte	Key	0..4 | 255		
TotalFecCodewords	Unsigned64	R			
CorrectedFecCodewords	Unsigned64	R			
UnreliableFecCodewords	Unsigned64	R			
TotalMacFrames	Unsigned64	R			
MacCrcFailures	Unsigned64	R			

8.3.1.5.3 Run US Probes Test

The [MULPIv3.1] specification defines Upstream Data Profile Testing Bursts for measuring upstream data IUC.

Probes are special-purpose upstream bursts periodically sent by CMs to determine transmit pre-equalizer coefficients and to test the quality of the upstream signal. The DOCSIS 3.1 specifications define active and quiet probes. Active probes are used to obtain MER information and equalization coefficients from CM's transmissions. Quiet probes allow the CMTS to measure the upstream channel during "quiet" symbol times when no CM is actively transmitting, permitting accurate measurement of the underlying noise, intermods and ingress.

The CMTS has several options for generation of probe signals. The format of probes is controlled by the CMTS via MAP messages. There is currently no standard management interface defined to configure the probe formats used by the CMTS, or to obtain the information about probe formats currently used by the CMTS or the set of probe formats that the CMTS is capable to generate.

The CMTS periodically schedules active probe opportunities for each CMs or can be instructed via a MIB to probe a particular CM as part of a PNM test procedure. When the CMTS issues active probes, it can obtain MER information from CMs. The per subcarrier, per CM MER information collected from received probes is the primary data point for the PMA to compute upstream profiles. The volume of information gathered from probes can be quite large. A single OFDM channel with 3500 active subcarriers and 100 active CMs can generate over 2 MB of diagnostic data. That includes MER and pre-equalization coefficients.

[CCAP-OSSIv3.1] defines SNMP MIB objects to instrument PNM test procedures in which the CMTS gathers the diagnostic data from probes sent by a selected CM to a file. The defined test procedures allow for collection of per CM, per subcarrier, MER data from active probes. The PNM MIB can be used by the PMA to initiate tests and to

retrieve the granular MER data. The UML diagram of the upstream PNM objects defined from the [CCAP-OSSIv3.1] is presented in Figure 10.

8.3.1.6 Instantiate/Delete a New Data IUC

Refer to the DOCSIS 3.1 CCAP OSSI specification [CCAP-OSSIv3.1] for the description of the UsOfdmaChanDataIuc object and UsOfdmaMinislotCfg object defining the attributes required for creating an upstream data IUC. Figure 11 provides a model of the UML for these objects.

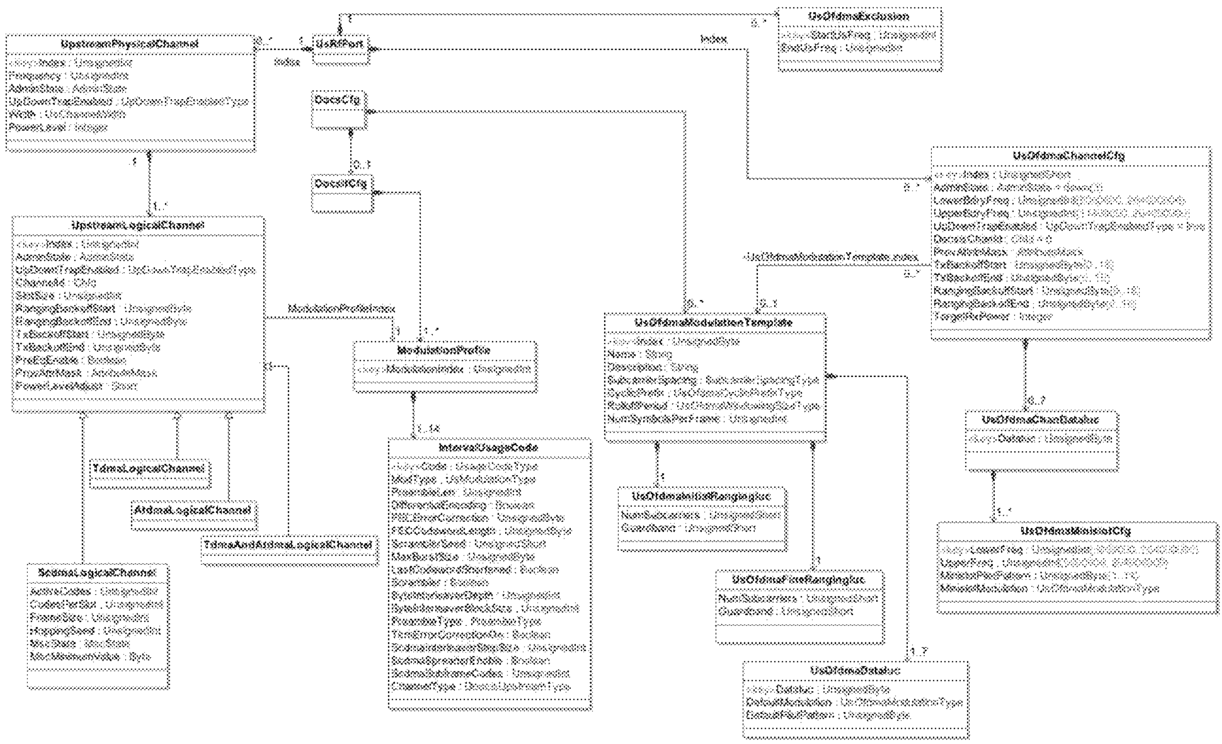


Figure 11 - DOCSIS Upstream Interface Configuration Model from [CCAP-OSSIv3.1]

8.3.1.7 Assign a Data IUC to a CM

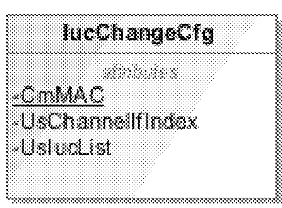


Figure 12 - DOCSIS Upstream Interface Assign Data IUC

Assigning a Data IUC could be modeled as follows:

IucChangeCfg

- CmMac: MAC address of the CM which needs to be assigned the IUC
- IfIndex: upstream OFDMA channel index
- UsIucList: List of IUCs to be assigned to the CM

8.3.1.8 Evaluate Target Test Data IUC

Test Data IUC is evaluated using the same test tools used to measure the channel as described in in previous sections about how to run upstream probe test and run data OUDP test.

The PMA Server evaluates whether Test IUC is better than existing IUC. The measures used are FEC errors and CRC errors. The metrics for good profiles would be Throughput, Correctable and uncorrectable FEC errors, CRC errors. Providing an interface into the PMA that allows operator to configure PMA algorithm for evaluating profiles is recommended.

8.3.2 Upstream PMA Data Model

The Upstream PMA Information Model is implemented as a set of YANG modules. PMA YANG modules are listed here: pma.yang , cl-pma-types.yang [PMA YANG]

This is meant to be an individual YANG Module (for both Upstream and Downstream PMA) which can be supported by a CMTS. Alternatively, it could be combined with the DOCSIS 3.1 CCAP YANG Model (ccap.yang [CCAPv3.1 YANG]). A CMTS would implement a RESTCONF (or NETCONF) interface to support this PMA YANG model. See Section 9.

8.3.3 Message Elements and Structure for a PMA-CMTS Interface

This section defines the type of messages and the message content needed for the PMA-CMTS interface for the upstream. This is a high level design of the interface. It identifies the kinds of data which need to flow back and forth and the operations which need to be supported for a PMA solution. This section is a generic framework for a PMA-CMTS interface. The actual YANG model was developed based on the requirements from this section.

These messages and the data needed are covered in the YANG data structures, for which the PMA-CMTS interface uses RESTCONF/NETCONF. An alternate implementation could define these as messages which could be carried back and forth using some other protocol (instead of RESTCONF/NETCONF). Table 1 provides a list of messages that are used for upstream channels.

Table 14 - PMA-CMTS Upstream Messages

Message	Description
Upstream OFDM Channel Descriptor	Conveys the configured channel parameters for an upstream DOCSIS 3.1 channel.
Upstream Profile(IUC) Request	Either a request from the CCAP for a new Profile(IUC) or a request from PMA for the details of an existing Profile(IUC).
Upstream Profile(IUC) Descriptor	Provides the configuration details of a modulation Profile(IUC).
Upstream Profile(IUC) Test Request (RxMER, OUDP Test Request)	Request from the PMA for the CCAP to test a specified modulation Profile(IUC). Request from the PMA for the a test to be run for a channel on a given CM.
Upstream Profile(IUC) Test Response (RxMER, OUDP Test Response)	Conveys the results of the test of a modulation Profile(IUC) on a specified CM. Response from the CMTS with results for the a test which was run previously for a channel on a given CM.
CM-to-Profile(IUC) Assignment Request	Request for a list of CMs that are assigned a specified modulation Profile(IUC).
CM-to-Profile(IUC) Assignment Descriptor	Provides a list of CMs that are or are to be associated with a modulation Profile(IUC).
Profile(IUC)-to-CM Assignment Request	Request for a list of the Profile(IUC)s that are assigned to a CM.
Profile(IUC)-to-CM Assignment Descriptor	Provides a list of channels and modulation Profile(IUC)s that are assigned or should be assigned to a CM.

Although a PMA may manage multiple CMTSs, it is assumed that each CMTS can be uniquely identified by its host IP address, which is in each message's header. So the message content defined here is within the context of a single CMTS. This section does not imply that the interface needs to use TLV-based messages. The intent of this section is to tease out the needed information exchange.

8.3.3.1 CMTS US Capabilities and PMA Configuration

DOCSISv3.1 technology defines many parameters and options. Not all of those parameters and options have to be supported by the CMTS. The CMTS may need to provide the PMA with information identifying its capabilities, for example, US burst receiver identification, which pilot patters are supported and power range.

Additional information may be useful to configure a PMA, for example:

- Constraints on IUCs, e.g., the range of bit loading values a CMTS supports.
- The number of IUCs that a CMTS supports per OFDM Channel.
- Constraints on the number of modulation order changes supported across minislots in one OFDMA channel.
- Constraints on the number of minislot pilot patterns supported by the CMTS.
- Constraints on a CM's bit loading ranges (if any).
- Other information that can be exchanged at boot time that is not channel-specific, e.g., topology information.

9 YANG MODEL DEFINITION

This section defines a standard object model for use with a profile management application. These data model requirements include the data object definitions, and functions to be invoked on a CMTS for profile management. These are aligned with the existing object models as defined in [CCAP-OSSIv3.1]. In addition, this also defines the standard Event Messaging/notifications requirements of a CMTS system, for the purposes of profile management.

9.1 Information Model : UML Diagram

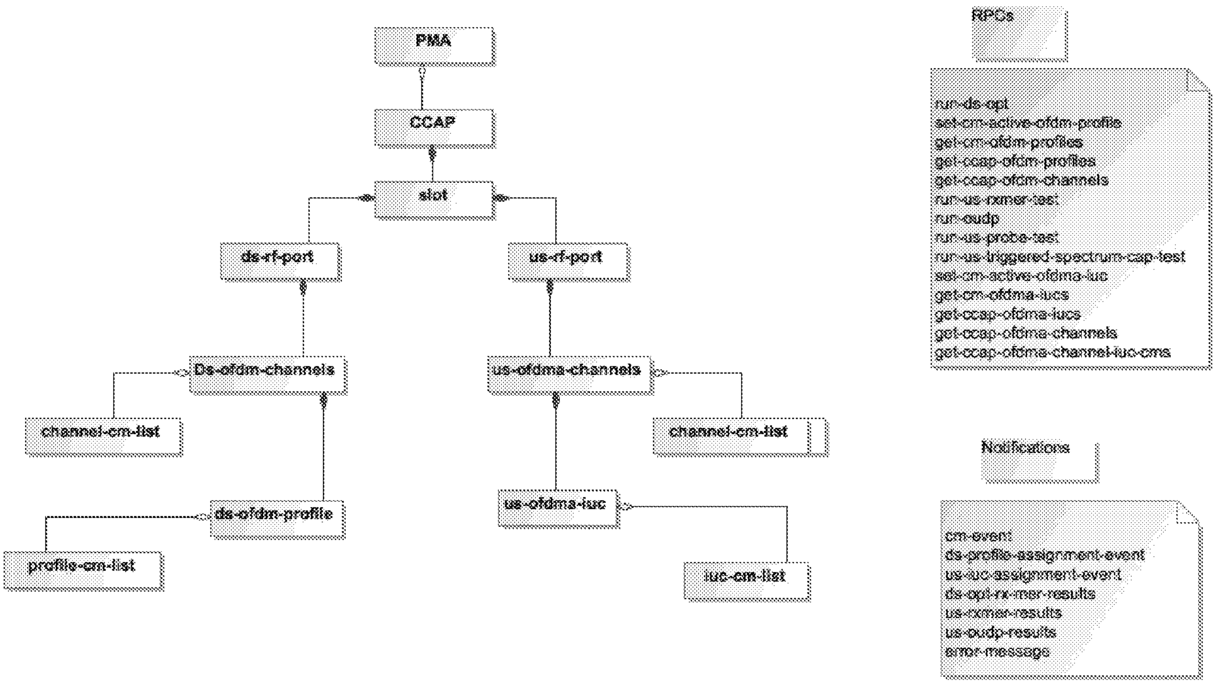


Figure 13 - PMA Information Model

9.2 Data Model: YANG Definition

The PMA YANG model is published here: http://mibs.cablelabs.com/YANG/DOCSIS/PMA/. A CMTS, in order to support an external PMA application, needs to support the PMA YANG module defined here.

The figures below show the data store hierarchy, remote procedure call (RPC) parameters and event notification details, as defined in the YANG model.

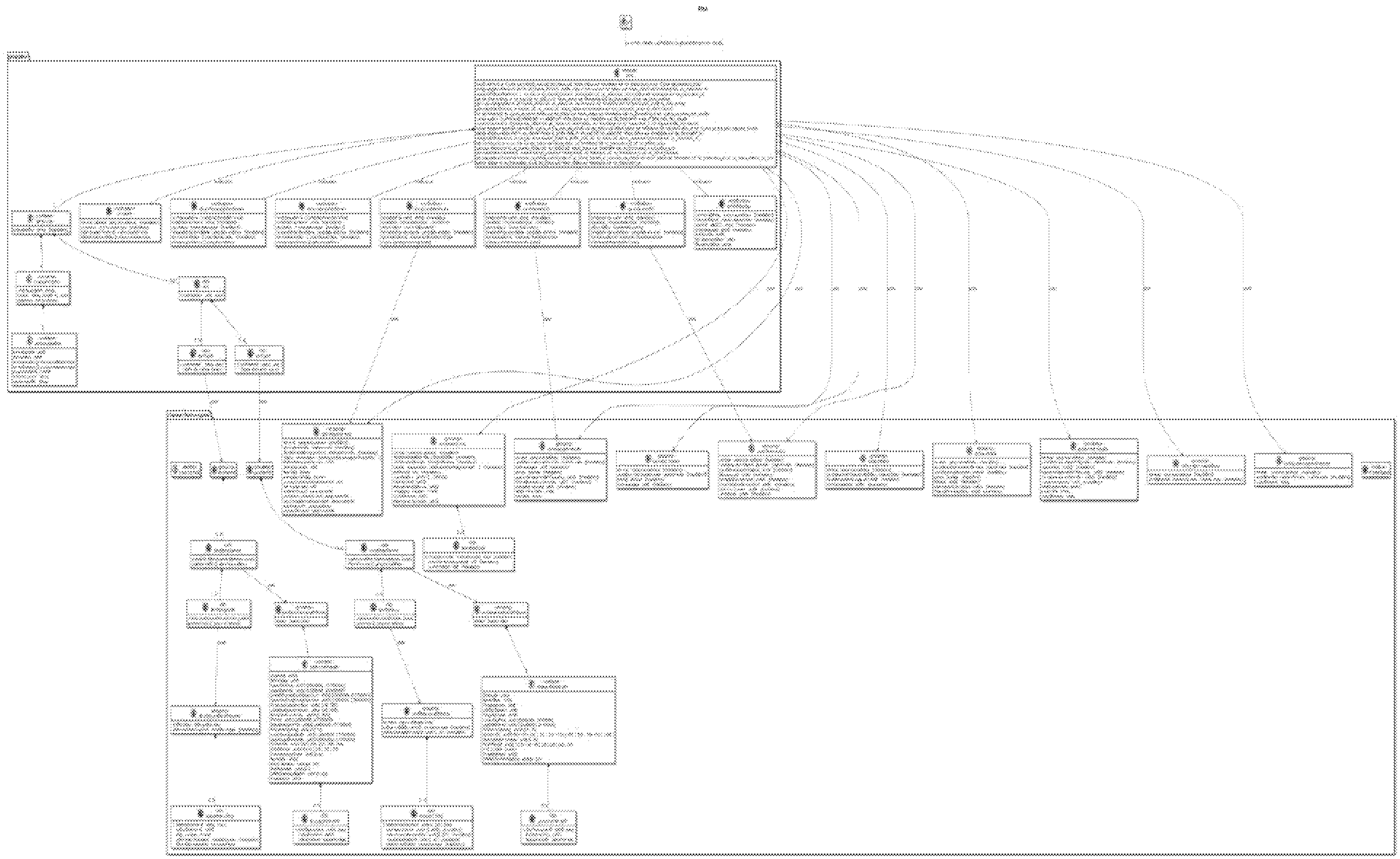


Figure 14 - PMA Data Model: Complete View

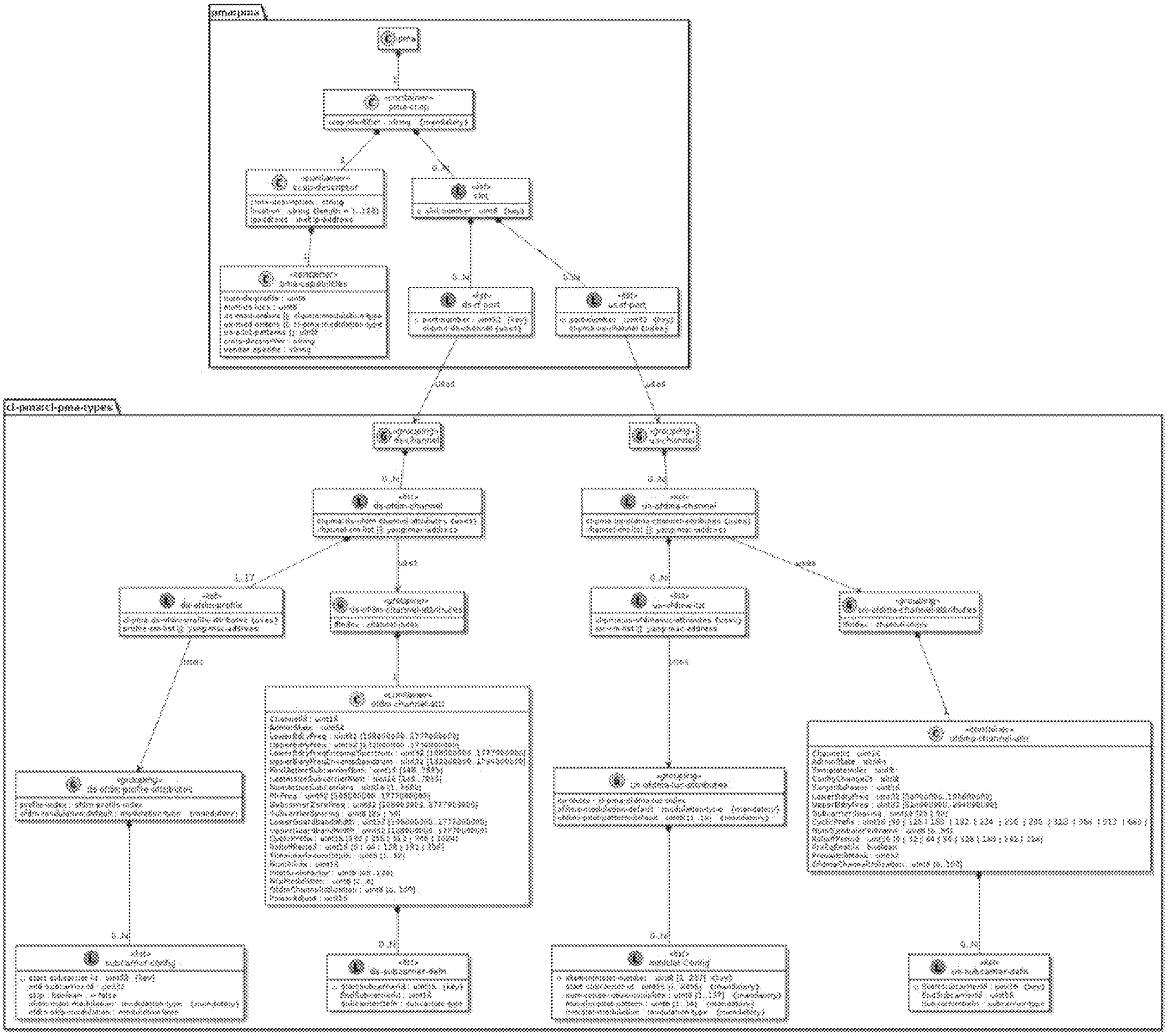


Figure 15 - PMA Data model: DataStore

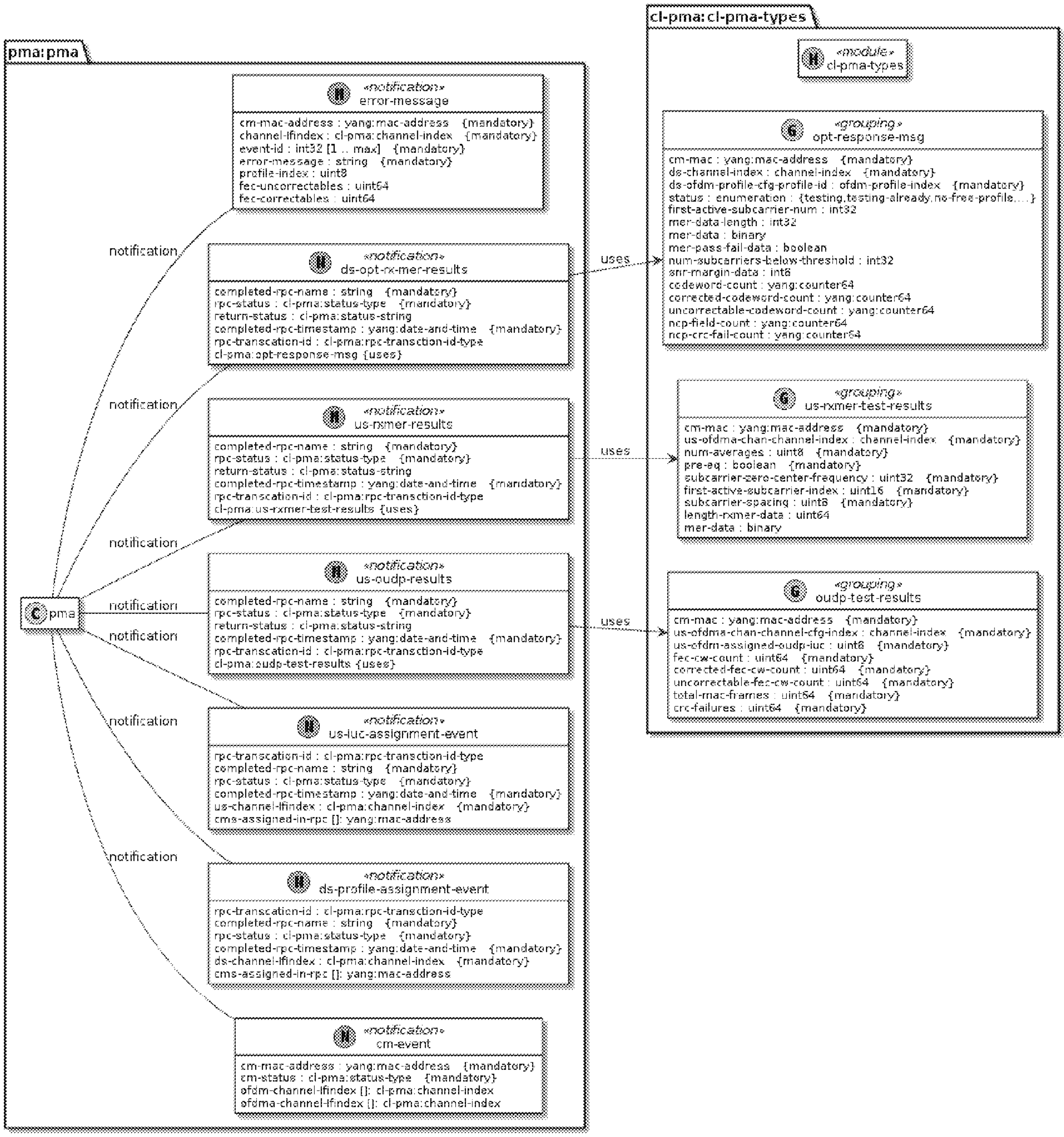


Figure 16 - PMA Data model: Notifications

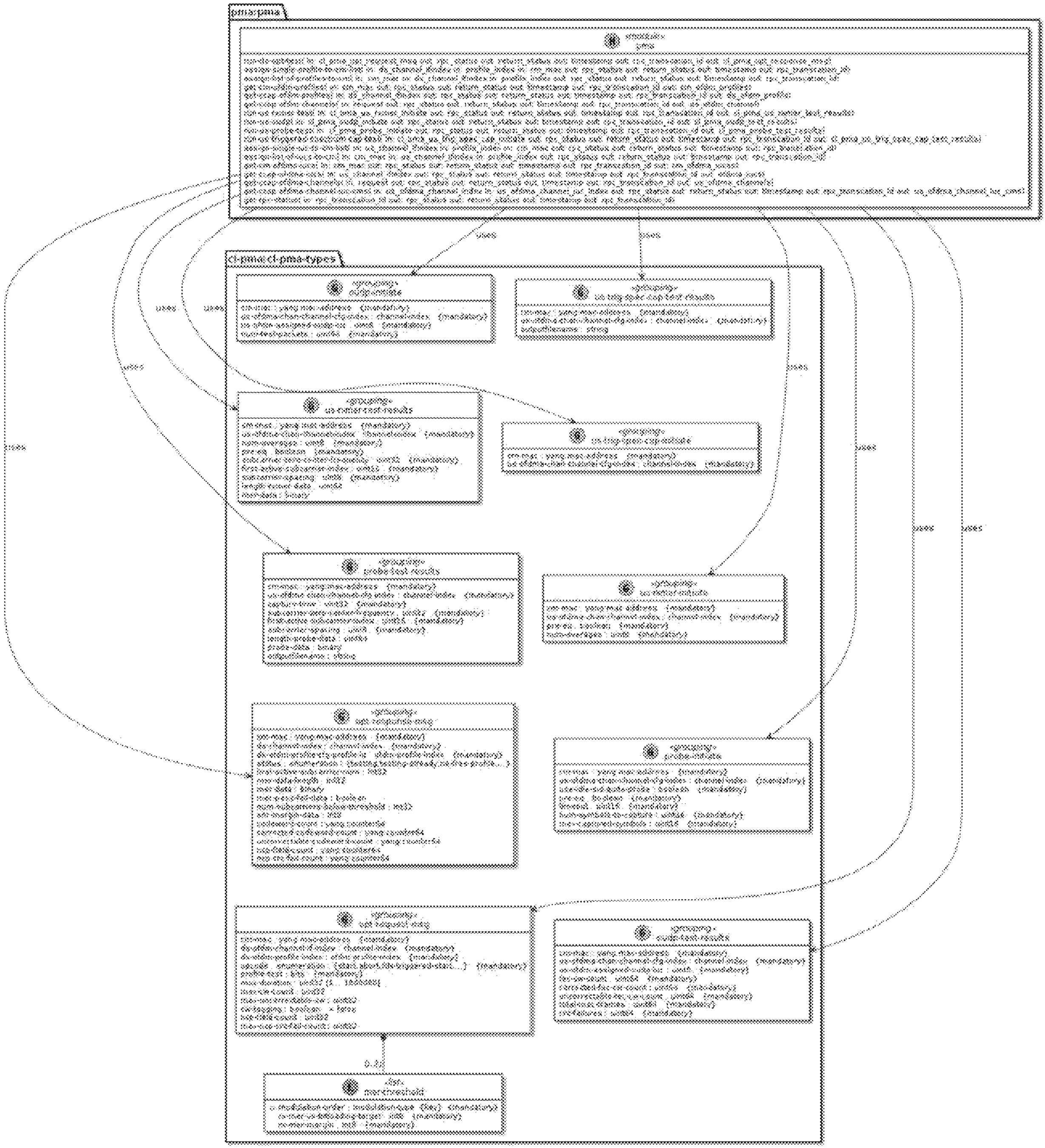


Figure 17 - PMA Data model: RPCs

10 PMA-CCAP INTERFACE PROTOCOLS

NETCONF and RESTCONF are proposed protocols for the PMA to access the necessary data and trigger the appropriate actions for profile management. NETCONF and RESTCONF are both designed for easy integration with YANG data models, making them suitable for operating with the CCAP OSSIv3.1 data model already defined in YANG.

10.1 NETCONF

NETCONF protocol [RFC 6241] provides mechanisms to install, manipulate, and delete configuration of network devices. It is designed to reduce programing effort involved in automating device configuration. NETCONF is based on secure transport and uses Extensible Markup Language (XML) based data encoding for configuration and state data as well as for protocol messages. The choice of data model language is independent. YANG [RFC 6020] is a recommended NETCONF modeling language, which introduces advanced language features for configuration management.

The NETCONF protocol is based on a Remote Procedure Call (RPC) model. The base protocol specifies a set of RPCs that clients invoke to manipulate configuration data stores, e.g., get-config, edit-config, copy-config, etc. The data modules implemented by the managed device specify additional RPCs that can be used by clients to manipulate specific device configuration and state data. The RPCs applicable to each data module are specified as part of the YANG definition of the module. NETCONF provides mechanisms for multi-action transaction management and two-phase commit, which assure data consistency at the cost of implementing a stateful session-based protocol with transaction semantics at the server side.

NETCONF can run over several transports including SSHv2, SOAP, and TLS. SSHv2 is the transport required by the base specification, with others being optional. NETCONF is defined in [CCAP-OSSIv3.1] as an optional configuration protocol for CCAP configuration management.

10.2 RESTCONF

RESTCONF is an HTTP-based protocol used to access data defined in YANG models using the data stores defined in NETCONF. RESTCONF is standardized in IETF RFC 8040 [RESTCONF]. RESTCONF supports both XML and JSON for encoding of the YANG-defined data. RESTCONF relies on Transport Layer Security (TLS) to provide privacy and data integrity between the application and server.

RESTCONF provides the CRUD operations on YANG defined models via the HTTP methods: OPTIONS, HEAD, GET, POST, PUT, PATCH, and DELETE. Configuration and operational data are represented as resources addressed via a URI, which can be retrieved with the GET method. Resources representing configuration data can be modified with the DELETE, PATCH, POST, and PUT methods. RESTCONF also employs YANG-defined Server-Sent event notifications for asynchronous notifications to clients.

The RESTful interface implemented by RESTCONF contrasts to the RPC-based method of NETCONF. The RESTCONF protocol operates on a hierarchy of resources, each of which represents a manageable component within the device. RESTCONF resources are accessed via well-defined URIs and the HTTP methods mentioned above. RESTCONF significantly reduces the transaction complexity of NETCONF. Each action on a resource is assumed to commit automatically on successful application and RESTCONF removes the option of two-phase commit.

For example, a NETCONF <get-config> RPC operation is implemented with a RESTCONF HTTP GET method, and a NETCONF <edit-config> operation=create RPC operation is implemented with a RESTCONF HTTP POST operation. For compatibility with YANG-managed data modules that export application-specific RPC actions for NETCONF, RESTCONF supports use of the HTTP POST method to invoke those RPC calls.

10.2.1 RESTCONF Security Model

RESTCONF employs two layers of security to protect access to sensitive network configuration and status data: a secure transport protocol supporting message integrity, confidentiality and authentication, plus data access security

to control access for specific RESTCONF users to pre-configured protocol operations and content (i.e., authorization).

RESTCONF is defined to run over HTTP with mandatory use of the TLS (Transport Layer Security) protocol (RFC 5246) with mutual authentication between RESTCONF clients and servers. TLS provides message integrity and privacy (encryption) across the RESTCONF TCP sessions. RESTCONF clients are required to validate the X.509 certificate presented by a RESTCONF server during connection setup using either standard certificate path validation or by matching the server certificate to a known trusted certificate. RESTCONF servers can authenticate the client either by validating an X.509 certificate presented by the client over TLS or by another HTTP-based challenge-response mechanism defined in the HTTP Authentication Scheme Registry, or both. The client identity derived from a successful RESTCONF client authentication is the "RESTCONF username" used to control access to protocol operations and data.

RESTCONF operation and data access control is based on the NETCONF access control model (NACM) defined in RFC 6536. In the NACM, access rights are granted to pre-configured group names and user names are assigned to groups. As mentioned above, RESTCONF user names are derived from the HTTP/TLS authentication exchange.

The NACM provides 4 types of access control rules that can be configured at the server:

- Access control to a specific YANG module, identified by its name.
- Access control to specific protocol operations, identified by YANG module and name.
- Access control to specific data nodes (or subtrees), identified by its path location within the XML document representation of the configuration or status data.
- Access control to specific notification event types, identified by YANG module and event name.

YANG models that specify the data managed by the RESTCONF server can include special NACM tags to apply default security modes to sensitive data in case no specific access control rule applies (e.g., "nacm:default-deny-write"). There are also configurable server global default access modes for read, write, and execute permissions. XML representations of example NACM group and access rule configurations at a NETCONF/RESTCONF server are found in RFC 6536 Appendix A.

10.2.2 Application of RESTCONF for Downstream PMA

The following table illustrates how PMA operations for downstream OFDM channels might be implemented by RESTCONF operations on a CCAP device or an SDN controller implementing the PMA YANG data model. Note that the PMA is always the HTTP client for all operations and the CCAP or SDN controller is the server. Any push-type operations toward the PMA are implemented as RESTCONF server event notifications. A new notification "stream" specific to PMA notifications must be defined (YANG model).

RESTCONF includes a root resource discovery capability that allows applications such as PMA to dynamically discover the root of the RESTCONF API resources supported by the server (e.g., the CCAP device). For simplicity the definitions and examples used in the remainder of this section assume that the RESTCONF API root is '/restconf'. As specified by the RESTCONF RFC, the top-level API resource contains 3 child resources:

- /restconf/data – contains all configuration and state data for all supported YANG models
- /restconf/operations – contains data-model specific operations (i.e., RPCs)
- /restconf/yang-library-version - contains the "ietf-yang-library" module date

Table 15 - PMA Downstream Operations using RESTCONF

DS PMA Operation (Sect 7.2, 7.3)	RESTCONF Method	Target URI(s)	Notes
Get List of DS OFDM Channels in use (PMA->CCAP)	GET	/restconf/data/pma:pma-ccap/slot=<s>/ds-rf-port=<p>/ds-ofdm-channel=<c>	Note that requesting element from ds-ofdm-channel list also returns all OFDM profiles for channel unless filtered out
(CCAP->PMA)	GET Response	N/A	Returns OFDM channel config block, including OFDM profiles for channel

DS PMA Operation (Sect 7.2, 7.3)	RESTCONF Method	Target URI(s)	Notes
Get list of DS Profile per OFDM Channel (PMA->CCAP)	GET (all) (specific)	/restconf/data/pma:pma-ccap/slot=<s>/ds-rf-port=<p>/ds-ofdm-channel=<c>/ds-ofdm-profile /restconf/data/pma:pma-ccap/slot=<s>/ds-rf-port=<p>/ds-ofdm-channel=<c>/ds-ofdm-profile=<i>	Retrieves list of OFDM profiles assigned to channel Retrieves specific OFDM profile assigned to channel (profile-index=i)
(CCAP->PMA)	GET Response	N/A	Returns list of OFDM profiles assigned to channel or individual profile
Configure DS Profile on a CMTS (PMA->CCAP)	PUT	/restconf/data/pma:pma-ccap/slot=<s>/ds-rf-port=<p>/ds-ofdm-channel=<c>/ds-ofdm-profile=<i>	Inserts or updates OFDM profile for specified channel at CCAP
Get list of CMs per OFDM channel (PMA->CCAP)	GET	/restconf/data/pma:pma-ccap/slot=<s>/ds-rf-port=<p>/ds-ofdm-channel=<c>/ds-ofdm-profile=<i>/profile-cm-list	
(CCAP->PMA)	GET Response	N/A	CCAP compiles list by walking docsIf3CmtsCmRegStatusTable MIB (DOCSISv3.1 extensions adds DS profile list);
Assign DS Data profile to set of CMs (PMA->CCAP)	POST or PUT	/restconf/data/pma:pma-ccap/slot=<s>/ds-rf-port=<p>/ds-ofdm-channels/ds-ofdm-channel=<c>/ds-ofdm-profile=<i>/profile-cm-list	Request Body includes one or more CM MAC address(es); Response includes status only.
Get a list of DS profiles in use by each CM for each OFDM channel (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:get-cm-ofdm-profiles	Request body includes input parameters: CM MAC Address
(CCAP->PMA)	POST Response (RPC)	N/A	Response Body includes output parameters: list of ofdm channels, profiles assigned to CM for each channel
Set the active Profile on an OFDM channel for CM(s) (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:assign-single-profile-to-cm-list /restconf/operations/pma:assign-list-of-profiles-to-cm	Request Body includes CM MAC Address and list of channel-profile mappings as described in Section 7.
Run DS OPT test on a CM (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:run-ds-opt-test	Request Body includes CM MAC Address, DS channel identifier, profile ID, and other test attributes.
(CCAP->PMA)	POST Response (RPC)	N/A	Response body includes the OPT output data

Example DS OFDM Channel Request From PMA->CCAP:

```
GET /restconf/data/pma:pma-ccap/slot=4/ds-rf-port=0/ds-ofdm-channel=405 HTTP/1.1\
Host: example-pma.com
Accept: application/yang.data+xml
```

Example DS OFDM Channel Response from CCAP->PMA

```
HTTP/1.1 200 OK
Date: Fri, 04 Mar 2016 17:02:40 GMT
Server: example-ccap
Content-Type: application/yang.data+xml
Last-Modified: Fri, 04 Mar 2016 11:02:14 GMT
```

```
<ds-ofdm-channel xmlns="urn:cablelabs:params:xml:ns:yang:pma">
        <IfIndex>405</IfIndex>
        <ofdm-channel-attr>
                <ChannelId>5</ChannelId>
                <AdminState>up</AdminState>
                <LowerBdryFreq>600000000</LowerBdryFreq>
                <UpperBdryFreq>696000000</UpperBdryFreq>
                <LowerBdryFreqEncompSpectrum>600000000</LowerBdryFreqEncompSpectrum>
                <UpperBdryFreqEncompSpectrum>696000000</UpperBdryFreqEncompSpectrum>
                <FirstActiveSubcarrierNum>148</FirstActiveSubcarrierNum>
                <LastActiveSubcarrierNum>3947</LastActiveSubcarrierNum>
                <NumActiveSubcarriers>3800</NumActiveSubcarriers>
                <PlcFreq>600000000</PlcFreq>
                <SubcarrierZeroFreq>600000000</SubcarrierZeroFreq>
                <SubcarrierSpacing>50</SubcarrierSpacing>
                <LowerGuardbandWidth>6000000</LowerGuardbandWidth>
                <UpperGuardbandWidth>6000000</UpperGuardbandWidth>
                <CyclicPrefix>256</CyclicPrefix>
                <RolloffPeriod>128</RolloffPeriod>
                <TimeInterleaverDepth>32</TimeInterleaverDepth>
                <NumPilots>128</NumPilots>
                <PilotScaleFactor>48</PilotScaleFactor>
                <NcpModulation>3</NcpModulation>
                <OfdmChannelUtilization>30</OfdmChannelUtilization>
                <PowerAdjust>0</PowerAdjust>
                <ds-subcarrier-defn>
                        <StartSubcarrierId>148</StartSubcarrierId>
                        <EndSubcarrierId>3947</EndSubcarrierId>
                        <SubcarrierDefn>1</SubcarrierDefn>
                </ds-subcarrier-defn>

                ... more ds-subcarrier-defns...

        </ofdm-channel-attr>
        <channel-cm-list>02:00:00:00:00:01</channel-cm-list>
                ...
        <channel-cm-list>02:00:00:00:00:0a</channel-cm-list>
        <ds-ofdm-profile>
                <profile-index>1</profile-index>
                <ofdm-modulation-default>qam1024</ofdm-modulation-default>
                <subcarrier-config>
                        <start-subcarrier-id>148</start-subcarrier-id>
                        <end-subcarrier-id>172</end-subcarrier-id>
                        <skip>false</skip>
                        <ofdm-main-modulation>qam2048</ofdm-main-modulation>
                        <ofdm-skip-modulation>qam2048</ofdm-skip-modulation>
                </subcarrier-config>

                ... more subcarrier-configs...

                <profile-cm-list>02:00:00:00:00:01</profile-cm-list>
                                ...
                <profile-cm-list>02:00:00:00:00:0a</profile-cm-list>
        </ds-ofdm-profile>

        ... more ds-ofdm-profiles...

</ds-ofdm-channel>
```


10.2.3 Application of RESTCONF for Upstream PMA

The following table illustrates how PMA operations for upstream OFDMA channels might be implemented by RESTCONF operations on a CCAP device or an SDN controller implementing the PMA YANG data model. Note that the PMA is always the HTTP client for all operations and the CCAP or SDN controller is the server. Any push-type operations toward the PMA are implemented as RESTCONF server event notifications. A new notification "stream" specific to PMA notifications must be defined (YANG model).

Table 16 - PMA Upstream Operations using RESTCONF

US PMA Operation (Sect 8.2,8.3)	RESTCONF Method	Target URI(s)	Notes
Get list of US OFDMA Channels in use (PMA->CCAP)	GET	/restconf/data/pma:pma-ccap/slot=<s>/us-rf-port=<p>/us-ofdma-channel=<c>	Note that requesting element from us-ofdma-channel list also returns all OFDMA profiles for channel unless filtered out
US OFDMA Channel Descriptor (CCAP->PMA)	GET Response	N/A	Returns OFDMA channel config block, including OFDMA profiles/IUCs for channel
Get List of US Profile/IUC per OFDMA channel (PMA->CCAP)	GET (all) (specific)	/restconf/data/pma:pma-ccap/slot=<s>/us-rf-port=<p>/us-ofdma-channel=<c>/us-ofdma-iuc /restconf/data/pma:pma-ccap/slot=<s>/us-rf-port=<p>/us-ofdma-channel=<c>/us-ofdma-iuc=<i>	Retrieves list of OFDMA profiles assigned to channel Retrieves specific OFDMA profile assigned to channel (profile-index=i)
US Profile Descriptor (CCAP->PMA)	GET Response	N/A	Returns list of OFDMA profiles assigned to channel or individual profile
Configure an US Profile/IUC (PMA->CCAP)	PUT	/restconf/data/pma:pma-ccap/slot=<s>/us-rf-port=<p>/us-ofdma-channel=<c>/us-ofdma-iuc=<i>	Inserts or updates OFDMA profile for specified channel at CCAP
Get list of CMs per OFDMA Channel (PMA->CCAP)	GET	/restconf/data/pma:pma-ccap/slot=<s>/us-rf-port=<p>/us-ofdma-channel=<c>/us-ofdma-iuc=<i>/iuc-cm-list	Retrieves list of CMs assigned to each IUC for the specified OFDMA channel
(CCAP->PMA)	GET Response	N/A	CCAP compiles list by walking docsIf3CmtsCmRegStatusTable MIB (DOCSISv3.1 extensions adds US profile list);
Assign an US data IUC/profile to set of CMs (PMA->CCAP)	POST or PUT	/restconf/data/pma:pma-ccap/slot=<s>/us-rf-port=<p>/us-ofdma-channel=<c>/us-ofdma-iuc=<i>/iuc-cm-list	Request Body includes one or more CM MAC address(es); Response includes status only.
Get list of upstream data IUC in use by each CM for each channel (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:get-cm-ofdma-iucs	Request body includes input parameters: CM MAC Address
(CCAP->PMA)	POST Response (RPC)	N/A	Response Body includes output parameters: list of ofdma channels and IUCs assigned to the CM for each ofdma channel
Set the Active IUC on an OFDMA channel for CM(s) (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:assign-single-iuc-to-cm-list /restconf/operations/pma:assign-list-of-iucs-to-cm	Request Body includes CM MAC Address and list of channel-profile mappings as described in Section 8.
Run OUDP Test (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:run-us-oudp	Request Body includes CM MAC Address, US channel identifier, IUC ID, and number of test packets.
(CCAP->PMA)	POST Response (RPC)	N/A	Response body includes the OUDP output data
Run Upstream Probe Test (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:run-us-probe-test	Request Body includes CM MAC Address, US channel identifier, and other test parameters
(CCAP->PMA)	POST Response (RPC)	N/A	Response Body includes the probe test results

US PMA Operation (Sect 8.2,8.3)	RESTCONF Method	Target URI(s)	Notes
Run Upstream RxMER Measurements test (PMA->CCAP)	POST (RPC)	/restconf/operations/pma:run-us-rxmer-test	Request Body includes CM MAC Address, US channel identifier, and other test parameters
(CCAP->PMA)	POST Response (RPC)	N/A	Response Body includes the RxMER test results
Run Upstream Triggered Spectrum Capture test (PMA->CCAP)	POST (RPC)	/restconf/operations/pma: run-us-triggered-spectrum-cap-test	Request Body includes CM MAC Address, US channel identifier, and other test parameters
(CCAP->PMA)	POST Response (RPC)	N/A	Response Body includes a pointer to the test results

10.2.4 Asynchronous Notifications

As described in Section 6, it may be inefficient for a PMA to be constantly polling the CMTS to determine when the state of the network changes, such as when a channel comes up or down, or when a CM arrives or leaves. As an alternative, the CMTS can support a "push" model, where event notifications are sent out asynchronously to interested listeners as these network-impacting events occur.

One method to implement CMTS event notifications utilizes RESTCONF Notifications, which in turn are based on W3C Server-Sent Events. In this model, the RESTCONF server (CMTS) makes a list of event streams that it supports available to RESTCONF clients at the stream list URL. The client retrieves the supported event streams list using the HTTP GET operation for the stream list URL, to which the CMTS server responds with the list of supported event streams, their characteristics, and their locations (URIs). The client then "subscribes" to a desired event stream by issuing a GET request for the location URL with the "Accept" type "text/event-stream". The CMTS then responds with a stream of events, continuing until either side closes the associated TCP connection.

For example, consider an event stream of "CM events" that the CMTS publishes to interested listeners such as the PMA. The PMA finds the location of the "CM events" stream with the following GET request.

```
GET /restconf/data/ietf-restconf-monitoring:restconf-state/streams HTTP/1.1
Host: example-ccap
Accept: application/yang.data+xml
```

The CMTS sends following response:

```
HTTP/1.1 200 OK
Content-Type: application/yang.api+xml
<streams_xmlns="urn:ietf:params:xml:ns:yang:ietf-restconf-monitoring">
<stream>
<name>CM-Events</name>
<description>CM event stream </description>
<replay-support>false</replay-support>
<access>
<encoding>xml</encoding>
<location>https://example-ccap/streams/CM-Events</location>
</access>
</stream>
```

… more available streams

```
</streams>
```

The PMA then subscribes to the "CM events" stream with a GET request to the CMTS stream URL:

```
GET /streams/CM-Events HTTP/1.1
Host: example-ccap
Accept: text/event-stream
Cache-Control: no-cache
Connection: keep-alive
```

The CMTS can then stream events to the PMA for as long as the TCP connection remains open:

```
HTTP/1.1 200 OK
Content-Type: text/event-stream
<notification
xmlns="urn:ietf:params:xml:ns:yang:ietf-restconf">
<event-time>2016-05-27T00:01:00Z</event-time>
<event xmlns="urn:cablelabs:params:xml:ns:yang:ccap:cm-events">
<event-class>cm-online</event-class>
<cm-identifier>00:1D:CE:01:23:45</cm-identifier>
```

… more info about the event…

```
<severity>info</severity>
</event>
</notification>
.
.
<notification
xmlns="urn:ietf:params:xml:ns:yang:ietf-restconf">
<event-time>2016-05-27T00:01:30Z</event-time>
<event xmlns="urn:cablelabs:params:xml:ns:yang:ccap:cm-events">
<event-class>cm-offline</event-class>
<cm-identifier>00:1D:CE:01:23:45</cm-identifier>
```

… more info about the event…

```
<severity>info</severity>
</event>
</notification>

[TCP connection closed]
```

Note that the event stream and event notification structure shown above is only an example. For definition of the actual event streams, events, and their structure to be supported by a CMTS for PMA, see [PMA YANG]. These will be extended in the future as need arises.

Table 17 - PMA Notifications in RESTCONF

PMA Notifications (From CMTS to PMA)	RESTCONF Method	Target URI(s)	Notes
CM Event	GET	/restconf/events/…/pma:cm-event	Event sent when a CM comes online or goes offline, along with DS and US channel IDs
DS Profile Assignment	GET	/restconf/events/…/pma:ds-profile-assignment-event	Event sent when an RPC to assign profile(s) to CM(s) completes. (Could be success or failure status)
US Profile Assignment	GET	/restconf/events/… /pma:us-iuc-assignment-event	Event sent when an RPC to assign IUCs(s) to CM(s) completes. (Could be success or failure status)
DS RxMER results	GET	/restconf/events/… /pma:ds-opt-rx-mer-results	Event sent when an RPC to test DS RxMER on CM(s) completes. (Contains RxMER values)
US RxMER results	GET	/restconf/events/…/pma:us-rxmer-results	Event sent when an RPC to test US RxMER from CM(s) completes. (Contains RxMER values)
US OUDP results	GET	/restconf/events/… /pma:us-oudp-results	Event sent when an RPC to test US OUDP from CM(s) completes. (Contains FEC stats etc.)
Generic Error message	GET	/restconf/events/… /pma:error-message	Event sent when a CMTS detects errors on a CM having crossed an event threshold. (e.g., number of FEC errors)

11 PMA DATA ACQUISITION

11.1 Overview

As discussed in previous sections, the PMA uses data from both the CM and CMTS to make decisions and modifications to the profiles that are available and then assigned to CMs on a given DS OFDM channel. The CCAP and CM OSSI 3.1 specifications have objects for Proactive Network Maintenance as well as the CMTS OPT MAC Management Message for gathering data like the MER values per OFDM subcarrier, the codeword errors, SNR values for the channel among many. Previous sections have talked about the messaging and the data models. This section focuses on the mechanics of how the data is obtained by the PMA.

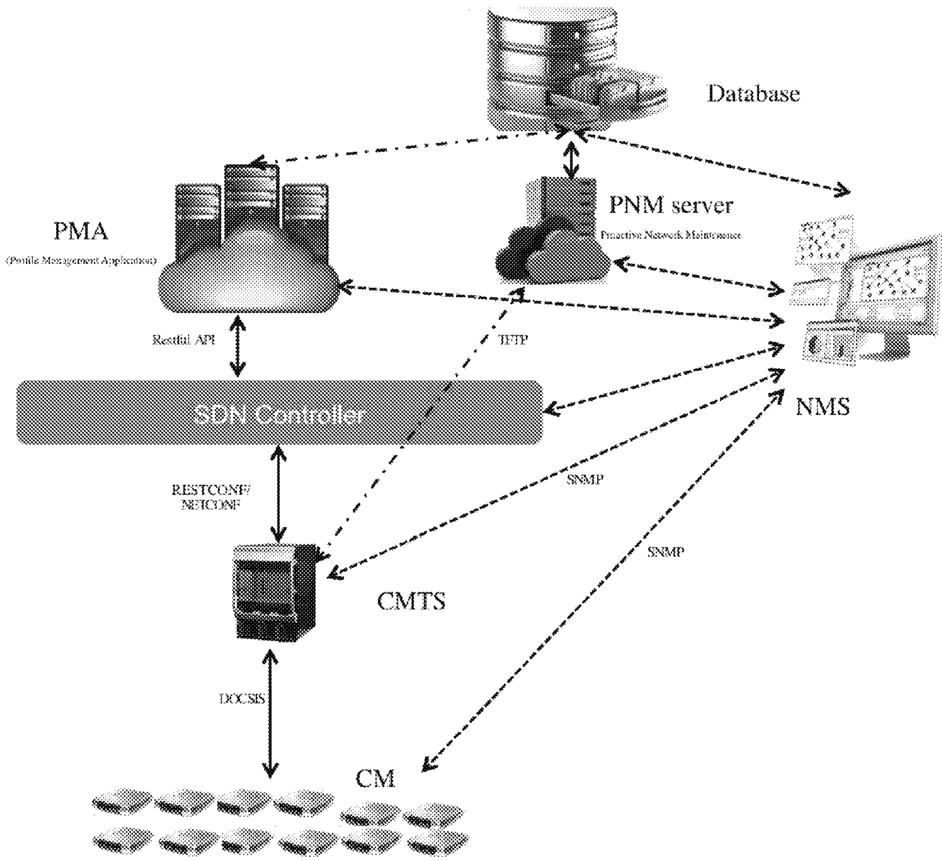


Figure 18 - PMA Data Interfaces

11.1.1 Data Needed by PMA

The PMA needs a wide variety of data in order to build the inventory of Downstream OFDM and Upstream OFDMA channels, their associated profiles or IUCs and then the CMs that have been assigned those channels and profiles/IUCs. Previous sections have described messaging between the CMTS and the PMA application that includes things like the OCD, DPD and UCD messages that the CMTS sends to each modem on ODFM downstream channels. Similar data can also be acquired from the DsOfdmChannelStatus, UsOfdmaChannelStatus objects defined in [CCAP-OSSIv3.1]. Associated profiles statistics such as the number of codewords can be obtained by accessing the docsIf31CmtsCmDsOfdmProfileStatus and UsOfdmaChannelDataIucStats Object or MIB. The docsIf31CmtsDsOfdmChan, docsIf31CmtsDsOfdmChan Objects provides the PMA with the physical characteristics of each DS/US OFDM/A channel that has been configured. To get information on the configured profiles created for each DS OFDM channel, the PMA uses the information in the DsOfdmProfileCfg object to view the previously created profiles. To get information on the configured profiles created for each US OFDMA channel, the PMA uses the information in the UsOfdmaDataIuc object to view the previously created profiles/IUCs. The

docsIf31CmtsDsOfdmSubcarrierType, docsIf31CmtsUsOfdmaSubcarrierType Objects provide information regarding the modulations or bit-loading capabilities of each of the subcarriers assigned in a given profile. The docsIf31CmtsDsOfdmProfileStats, docsIf31CmtsUsOfdmaIUCStats Object provides detailed information regarding the traffic usage for a specific profile assigned to a specific DS/US OFDM/A Channel.

The docsIf31CmtsCmRegStatusTable is an augmentation of the earlier DOCSIS 3.0 CmtsCmRegStatus table and includes data elements like the docsIf31CmtsCmRegStatusDsProfileIdList, docsIf31CmtsCmRegStatusUsProfileIucList which can help the PMA to identify which DS/US Profiles are currently assigned to the CM.

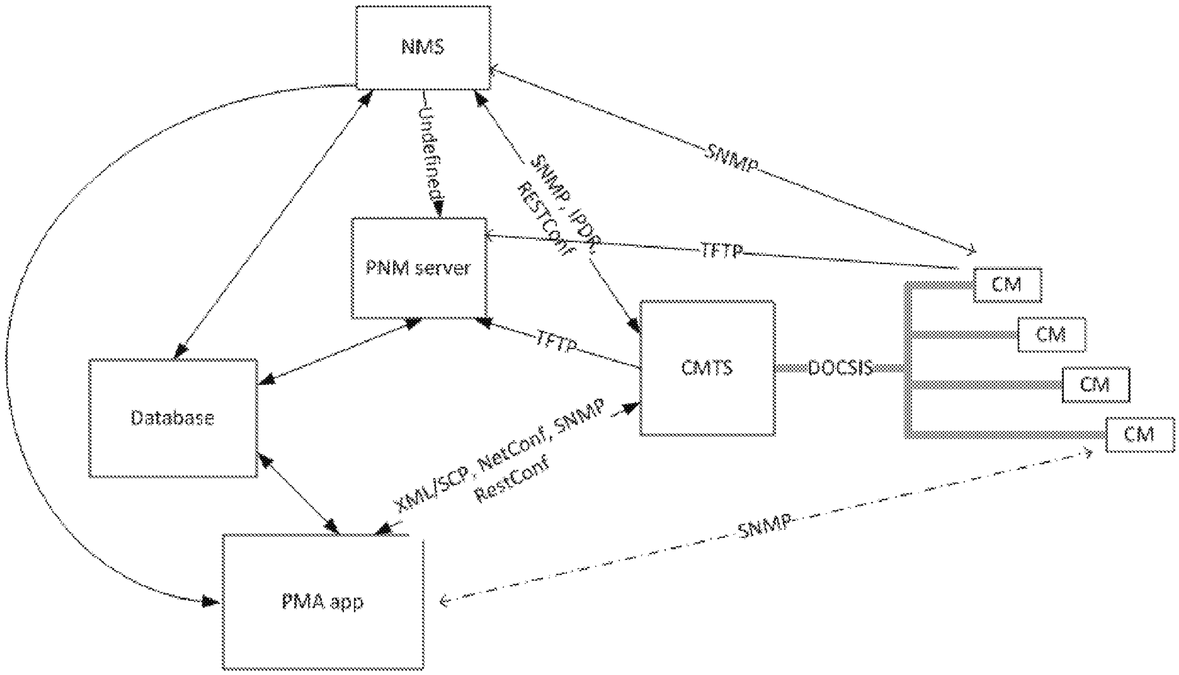


Figure 19 - PMA Data Backend and Protocols

Figure 19 shows the various protocols and locations/devices from which the data needed for a PMA application can be obtained.

The PMA needs the following information to come up with profile recommendations.

- Channel Configuration information:
  - OCD parameters, list of profiles and CMs assigned to each, the DPD information for each profile;
  - UCD parameters, list of IUCs and CMs assigned to each, the IUC information for each profile.
- DS CM Performance data:
  - OFDM Profile Test (OPT) data - Performance of a CM on a particular profile.
  - CM performance-related information (e.g., FEC statistics, packet counts (total/error), etc.) - (Obtained from the CMs or from the Network Management System (NMS))
  - Profile traffic statistics (e.g., transmitted byte counts) - (Obtained from the NMS).
- US (CMTS) Performance data:
  - Performance of a CM on a particular IUC.
  - CM performance-related information (e.g., FEC statistics, packet counts (total/error), etc.) - (Obtained from the CMTS or from the Network Management System (NMS))
  - IUC traffic statistics (e.g., transmitted byte counts)

The PMA may also obtain other information from sources other than the CMTS, e.g., previous history for this plant segment/frequency range from DOCSIS 3.0 channels/CMs that have used it, from an earlier DOCSIS 3.1 channel, or from PNM metrics such as spectrum captures gathered from other devices using other frequencies on the plant.

11.2 Obtaining DS MER Data from Modems

11.2.1 Use of OPT to Obtain Cable Modem Downstream MER data

The OPT request message can be used to gather per subcarrier receive MER data from a CM. Several tests can provide the PMA with detailed information on a per-channel or per-test profile basis. The test RxMER Statistics per Subcarrier can provide the specific measured MER for each active subcarrier in the specified DS OFDM channel regardless of the currently assigned profiles. The RxMER per Subcarrier Threshold Comparison for Candidate Profile test allows the CM to make a measurement based on a target profile (un-assigned). This test has specific target MER values that the Operator has configured for each modulation order in the target profile. When the CM is requested to perform this test, the CM takes the RxMerVsBitloadingTarget values, compares those with the measured MER for a specific subcarrier, and determines the number of subcarriers that are above or below that value. The PMA application can then use this data to determine the performance of a given modulation order on a given subcarrier. The SNR Margin for Candidate Profile test measures the SNR margin between the required value (RxMerVsBitloadingTarget) and RxMerMargin.

11.2.2 Proactive Network Maintenance (TFTP from modem)

Another method that can be used to obtain MER data from the CM is to query the CM directly using the Proactive Network Maintenance MIBs defined in the [CM-OSSIv3.1] specification. Using the DsOfdmRxMer object [CM-OSSIv3.1], the PMA requests the per subcarrier MER data from the CM. This MIB is designed to return this data back in the form of a file that is TFTP'd to an external PNM or PMA server.

11.2.3 Obtaining Codeword Performance Data from the CM

Another key profile performance metric is the codeword error rates for a given profile. This data can be obtained from the CM via the CMTS OPT messages or via the PNM MIBs on the CM. The following sections describe the two methods that the PMA can employ to gather this data.

11.2.3.1 Obtaining Codeword data using OPT

To obtain the codeword statistics from the CM using the OPT message, the PMA requests either the Codeword Statistics for Candidate Profile or the Codeword Threshold Comparison for Candidate Profile or both. These tests return the total Codeword Count, the Corrected Codeword Count and the Uncorrectable Codeword Count for the target or active profile. If this test is run on a target or test profile, the CMTS uses data packets it generates for the tests. If the profile is an active profile, the CM reports statistics based on actual traffic. These tests can be run over a specific duration or while a specific number of codewords is recorded.

11.2.3.2 Obtaining Codeword data using PNM MIBs on the CM

The CmDsOfdmProfileStats object [CM-OSSIv3.1] can be used to retrieve statistics from the CM on a per-channel, per-profile basis.

11.3 Obtaining US MER Data from CMTS

11.3.1 Proactive Network Maintenance (TFTP from CMTS)

One method that can be used to obtain MER (or other PNM) data from the CMTS is to query the CMTS directly using the Proactive Network Maintenance MIBs defined in the [CCAP-OSSIv3.1] specification. Using the UsOfdmaRxMerPerSubcarrier object [CCAP-OSSIv3.1], the PMA requests the per subcarrier MER data from the CMTS. This MIB is designed to return this data back in the form of a file that is TFTP'd to a PNM or PMA server.

12 OTHER PMA CONSIDERATIONS

12.1 Central Database

The information exchange between the CMTS and the PMA is the key enabler for this application. This information can be exchanged in real time between the PMA and the CMTS.

Another approach to ease the communication burden on the reporting entities could be to implement a central database which is updated with all the information. An SDN controller could host a master database to capture all the information exchange needed for this application. This database can hold all the information needed by a PMA, the profiles used and their details, which CMs are using which profiles, historical profile, and usage information. This gets updated every so often by the CMTS or by pulling data from other sources (e.g., PNM data).

12.1.1 Types of Data Needed

There are various kinds of information needed by a PMA to compute the optimal profiles. All the needed data can be stored in a database accessed by the SDN controller, so that it could be used by multiple applications. The following is a list of the different kinds of data that can be useful to store in a database:

- CMTS registration information (when it connects with an SDN controller)
- PMA initial configuration information
- Current CMTS OFDM channel configurations
- List of all CMs that are online, and the CMs on the same OFDM Channel
- List of profiles in use by each CM
- Historical data (e.g., profile configurations which were used, not accepted, etc.)
- Signal Quality Analytics for each Downstream Channel on the CMTS:
  - MER info from CMs
  - Data obtained from the OPT-RSP messages from a CM (see [MULPIv3.1])
  - Statistics: FEC statistics (e.g., LDPC), CRC statistics, and MAC Layer statistics
  - Proactive Network Maintenance (PNM) data from a CM (see section on PNM in [PHYv3.1])
  - Data from the Symbol Capture function on a CM and a CMTS; this data can be used to figure out the transfer function of a channel

12.2 Multiple Masters Problem

Once a PMA application is implemented, more than one entity can configure profiles to be used. In this case, both the CMTS and the PMA have the ability to calculate optimal profiles and configure the needed changes on the plant. The current design assumes that the PMA essentially makes suggestions or recommendations to the CMTS, which the CMTS can choose to implement or decline.

At this point, the higher-level understanding is that the CMTS can be autonomous, i.e., it does not have to use the PMA for all the use cases described previously, all the time (or for any of the use cases). In the future, a model where the PMA takes over absolute control of managing all the profiles on the CMTS can be considered.

12.3 Evaluating Profile Changes

Once the PMA and CMTS implement the profile changes, the system needs to be monitored and evaluated on the effect of the changes. The throughput of each individual CM and the packet errors need to be measured to evaluate how each CM is performing on their assigned profiles. The network capacity also needs to be monitored and measured to evaluate if the profile changes were optimal in terms of maximizing the network capacity. These responsibilities will typically be shared between the CMTS and the PMA. This would require real-time

responsiveness on the PMA and implementation of intelligent algorithms, which can be configured with policies from the operator.

12.4 Policy Definition

Changing a profile could cause temporary traffic interruptions for a CM. There are many situations in which a PMA or a CMTS will be unable to make a change to the profile assigned to a CM. This may be because the CM is running services like video streaming or supporting a voice call at that moment and service continuity is more important to the operator at that time compared to the positive effects of a profile change. All of these use cases need to be captured as a set of policy rules. These would be exposed as APIs for Policy Enforcement, for Policy Deployment, and for status reporting. This policy will be defined by an MSO during initialization of the PMA. During runtime, the CMTS or the PMA checks for service interruption policy (or other conditions) before implementing a profile change.

12.5 Data Acquisition Methods

The choice for the PMA is to either reuse existing mechanisms of data retrieval from the CM or the CMTS, or to require support of new protocols such as RESTCONF (as described in Section 7.2) on a CMTS.

The data from the CMTS and the CMs can be acquired in one of many ways. These include SNMP MIB reads, MAC Management Messages, FTP data out of CM to a PNM server, or all the data and commands flow through the RESTCONF interface on the CMTS.

There needs to be further analysis and design of what are the best mechanisms for sending data back and forth between a CMTS and the PMA.

12.6 Data Volume for Message Exchanges

The relevant messages for profile management are described in the following subsections.

12.6.1 Downstream Profile Descriptor

There is one downstream profile descriptor per profile, and it consists of:

- MMM header + 1 byte DS Channel ID + 1 byte profile ID + 1 byte config change count
- Subcarrier assignment TLV varies, up to 255 bytes
- Transmission Interval time - On PLC: 200-250 ms, On Profile A: 500-600 ms

12.6.2 OFDM Downstream Profile Test

- OPT-REQ: MMM header + 2 bytes reserved + 1byte DS Channel ID + 1byte profile ID + 1byte opcode
- OPT-RSP: (see the "OPT-RSP TLV Encodings" Table in [MULPIv3.1])
  - MMM header + 2 bytes reserved + 1byte DS Channel ID + 1byte profile ID + 1byte opcode
  - 2N + 59 bytes (15419 bytes for N=7680)
- Test is performed per-CM and per-OFDM channel. The test transaction time is vendor-dependent. Also the CMTS needs to store the RxMER received.

12.6.3 Data Volume Estimate

The approximate uncompressed size for a profile is about 8 kB, (a list of modulation orders for each subcarrier).

The approximate compressed definition of a profile is about 180 bytes;
[a start frequency(4bytes), an end frequency(4bytes), modulation order(1byte)] * number of modulation order segments in a profile (20 segments, for example).

Storage needed for all the Profiles on all the channels on a CMTS:

- Number of OFDM Channels per CMTS: e.g., 10 Line cards with 7 OFDM channels each with 16 profiles each.
- A CM MAC address is 6 bytes long. In the example of a set of 200 CMs in a channel, to store the profile assignments the size is calculated as follows:
  6 bytes*200 CMs *4 profiles per CM*1 byte Profile ID = 4800 bytes
- The storage needed for the CMTS example above (for each option) would be:
  - 10*7* (16*8Kbytes + 4.8Kbytes) = 9296KB or ~10MB
  - 10*7*(16*180bytes+4800) = 537 KB or ~ 0.5 MB

Storage needed for tracking the Profile IDs assigned to each CM:

- The Number of profiles tracked per CM. If tracking an example of 3 candidate profiles (e.g., profile A, unicast profile, multicast profile) and Number of historical copies stored, the storage needed for this example would be: 5 bytes(a profileID + a Channel IfIndex) * 10K CMs * 3 profiles * 10 historical copies = ~1.5 MB.

12.7 Areas of Future Study in the PMA Solution

The design of the PMA needs further analysis in the following areas:

- The initialization of the PMA and CMTS needs to be thought through and designed in detail.
- How the PMA decides when to update profiles on a CMTS/CM. The PMA needs to decide when a CM should move to a lower or higher profile; this would be the PMA vendor's trade secret. The PMA could initiate a test on the current channel/RxMER (using MMM or PNM), get the required information, and then figure out recommendations on new profiles.
- CMTS vendors need to investigate the mechanics of implementing support for a PMA application function on an existing CMTS platform. Specifically, when to kick off DOCSIS messages based on commands from the PMA and how to extract information from MMMs, etc.
- Adjacent Spectrum Usage. How does the PMA make use of that information to create profiles? How spectrum is used next to an OFDM channel can change bit loading. This problem is discussed in the RPHY specs. Adjacent OFDM channel can cause roll offs, this has been seen in field data. For example, an SC QAM placed within OFDM; this would be an exclusion scenario within the OFDM channel. Or, if an SC QAM channel is next to an OFDM channel, this causes issues within channel or at edge of channel. Adjacent channel issues can arise between OFDM and SCQAM. PMA algorithms could use information about adjacent spectrum usage.
- If an operator choses, the PMA could get and evaluate data for the entire spectrum instead of just the MER data for just one channel. This way it can potentially place and configure all the channels on the CCAP optimally, add new OFDM/A blocks, etc. Event within a channel a PMA could be responsible for adding/removing sub carriers, and optimizing the configuration of a particular channel.
- Other PNM test procedures such as capture of probe data, the upstream histogram and impulse noise are of lesser applicability to OFDMA profile management. Other procedures exist such as upstream spectrum capture on any RF US port, (Upstream Triggered Spectrum Capture). The usability of the such data for PMA is left for further study.

As the industry develops profile management applications further and the data models and data collections mature, these areas will be addressed.

Appendix I Profile Evaluation Methods

I.1 Interfaces vs Algorithms

The goal of the profile creation and management algorithm is to analyze the channel conditions for each CM and then figure out the optimum set of profiles to configure for that channel. This technical report focuses on the interfaces between the PMA and the CMTS and the format of the data which flows back and forth. At this point, the technical report is not focused on the algorithms themselves that would be used by a PMA to design an optimum set of profiles.

I.2 PMA Algorithms

One example of what data a profile management algorithm can use and how it would actually work to design optimum profiles is defined in [NCTA-GWKS_PMA]. This details a few methods of grouping or clustering CMs with similar MER signatures in the channel and designing a profile for each one of these groups.

I.3 Profile Score

There needs to be a way to qualitatively rate the profile design rate or grade the profiles. One metric is the estimated channel data capacity in bits per sec. See [CCAP-OSSIv3.1] for definition and algorithms for calculating DOCSISv3.1 OFDM/OFDMA channel Capacity. There needs to be a way to compare profiles once designed, for resilience from error, deviation from ideal, margin etc. Each of these are determined by the operator and how much tradeoffs they are willing to make between individual CM capacity or overall channel capacity versus MER margin or FEC errors, etc.

I.3.1 CMTS Maintained Statistical Counters, a Metric for Profile Performance

The [CCAP-OSSIv3.1] defines a set of OFDMA status object and statistical counters maintained by the CMTS. These counters are related to OFDMA performance and available via DOCS-IF31-MIB. The set of statistical counters include per OFDMA channel, and per data IUC counts of Total codewords, Corrected codewords, Uncorrectable codewords, and Received octets.

The CMTS also maintains the following per CM per OFDM channel statistical counters: Receive Power, Mean Receive MER, standard Deviation of MER, threshold of receive MER, etc. The CMTS also maintains the following statistical counters per CM, per OFDM channel and per data IUC of Total codewords, corrected codewords, uncorrectable codewords. Finally, the CMTS implements a set of counters on MAC level. While many of these counters account data received on bonded flows from multiple channels, these counters can be used as the first diagnostic level (CRC errors, HCS errors, etc.).

Appendix II MER to QAM Mapping

II.1 Downstream

The PMA needs to be able to map RxMER values in the Downstream to an appropriate QAM level. These mappings are defined in [PHYv3.1] (*see Table 46 - CM Minimum CNR Performance in AWGN Channel*) and also the [CM-OSSIv3.1] (*see Table 72 - CmDsOfdmRequiredQamMer Object*). These mappings are summarized in Table 18 below.

Table 18 - DS RxMER to QAM Level mapping

Constellation/ Bit Loading	CNR/MER (dB)
16 QAM	15.0
64 QAM	21.0
128 QAM	24.0
256 QAM	27.0
512 QAM	30.5
1024 QAM	34.0
2048 QAM	37.0
4096 QAM	41.0
8192 QAM	*46.0*
16384 QAM	*52.0*

II.2 Upstream

The PMA needs to be able to map MER values in the Upstream to an appropriate QAM level. These mappings are defined in [PHYv3.1] (*see Table 18 - CMTS Minimum CNR Performance in AWGN Channel*). These mappings are summarized in Table 19 below.

Table 19 - US RxMER to QAM Level mapping

Constellation/ Bit Loading	CNR/MER (dB)
QPSK	11.0
8 QAM	14.0
16 QAM	17.0
32 QAM	20.0
64 QAM	23.0
128 QAM	26.0
256 QAM	29.0
512 QAM	32.5
1024 QAM	35.5
2048 QAM	39.0
4096 QAM	43.0

Appendix III DS Profile and US IUC examples

III.1 Downstream

The PMA will output profile definitions and assignment of a set of CMs to each profile. As an example the following figure illustrates the profiles(five profiles in the figure below, each one is a different color) along with their definition, (i.e. the modulation order) plotted in a graph across the frequency range of the channel. Different number of CMs will be associated with each profile. Profile A will be defined as the least common denominator profile for the channel and will be assigned to all CMs.

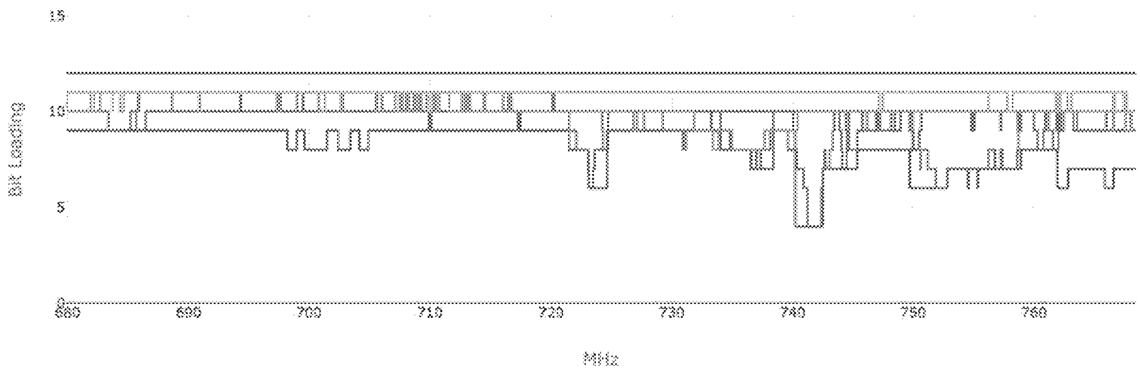


Figure 20 – DS Profile definitions (sample OFDM profiles for a 96 MHz downstream)

III.2 Upstream

The PMA will output IUC definitions and assignment of a set of CMs to each IUC. As an example the following figure illustrates a number of IUCs (five IUCs in the figure below, each one is a different color) with their definition, (i.e. the modulation order) plotted in a graph across the frequency range of the channel. Different number of CMs will be associated with each IUCs. Profile 13 will be defined as the least common denominator IUC for the channel and will be assigned to all CMs. The PMA will also recommend the minislot pattern for each US IUC (this not shown in the figure).

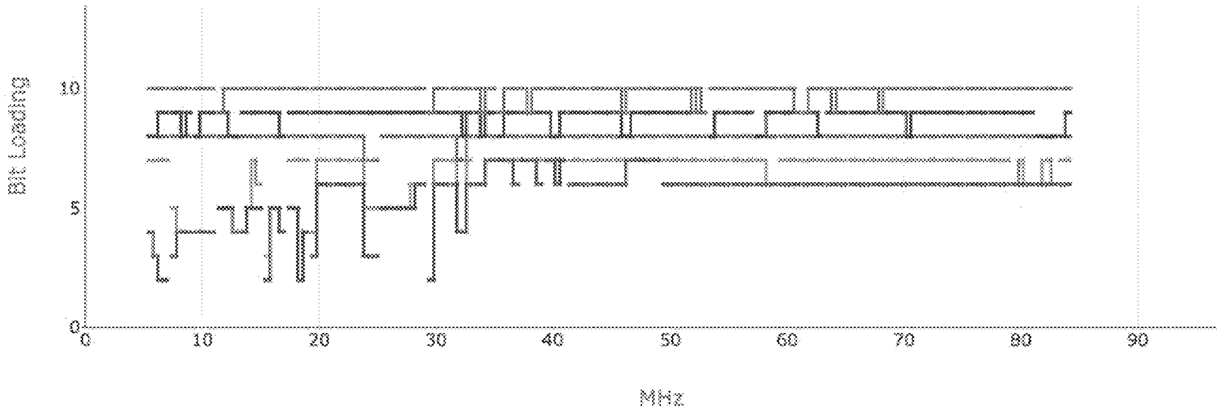


Figure 21 - US IUC definitions (sample OFDMA IUCs for a 80 MHz upstream)

Appendix IV DOCSIS 3.1 Upstream Channel Overview

US OFDMA channels are channels introduced in DOCSIS 3.1 specifications. A comprehensive description of the operation of OFDMA channels can be found in [PHYv3.1] and [MULPIv3.1]. The section titled "Upstream Transmit and Receive" in [PHYv3.1] describes the upstream transmissions of OFDMA channels that is relevant to the PMA application.

Upstream transmission uses OFDMA frames. Each OFDMA frame is comprised of a configurable number of OFDM symbols, *K*. Several [CMs] may share the same OFDMA frame by transmitting data and pilots on allocated sub-carriers of the OFDMA frame. The upstream spectrum is divided into groups of sub-carriers called minislots. Each group is 400 kHz of contiguous sub-carriers. Minislots have dedicated sub-carriers, all with the same modulation order ("bit loading"). A CM is allocated to transmit one or more minislots in a Transmission Burst. The modulation order of a minislot, as well as the pilot pattern to use may change between different transmission bursts and are determined by a transmission profile.

IV.1 Upstream Bit Loading

Increasing the bit loading of a minislot requires higher signal quality (higher signal-to-noise ratio, SNR) but allows the minislot to carry more bits of information. Varying the pilot pattern of a minislot is a trade-off between the overhead of sending pilots and the greater information provided to the CMTS for accurately receiving transmitted symbols from subcarriers within a minislot. Maximizing the effective upstream transmission of an OFDMA channel involves tuning the bit loading and the pilot pattern with the goal of maintaining reliability of transmitted symbols and maximizing the number of transmitted bits.

Additionally, DOCSISv3.1 technology describes TaFDM deployment of OFDMA channels and SC-QAM channels over overlapping frequencies. TaFDM enables the upstream spectrum to be fully utilized with the higher spectral efficiency of DOCSISv3.1 technology while maintaining backwards compatibility for DOCSISv3.0 CMs. In TaFDM operation, the CMTS coordinates the upstream access of DOCSISv3.0 modems and DOCSISv3.1 modems. Guard bands are applied in both frequency and time between OFDMA and SC-QAM channel schedulers such that the SC-QAM and OFDMA channels do not interfere with each other. When the PMA is operating with OFDMA channels that are part of a TaFDM deployment, the PMA's profile recommendations for OFDMA channels should be optimized for TaFDM deployment. The CMTS is required to maintain a guard band between adjacent SC-QAM and OFDMA channels to mitigate potential interference between the channels. The presence of an SC-QAM channel within an OFDMA channel could potentially require the use different modulation orders for OFDMA subcarriers adjacent to the SC-QAM channel.

The goal PMA is to determine the bit loading (modulation orders) per subcarrier needed to define an upstream profile/IUC to optimize channel efficiency given the channel conditions such as interference and noise.

IV.2 Upstream Pilot Patterns

US Pilot Patterns in US OFDMA operation are predefined sets of distributions of pilot signals within a minislot in upstream transmissions from the CM to CMTS. Each pilot consumes a symbol that would otherwise be carrying end-user data but provides the upstream receiver opportunities to perform channel estimation on the minislot. The optimal US Pilot Pattern depends on the rate and degree to which the transmission characteristics of the HFC plant change over time. In OFDMA channels with low channel variability, a small number of pilots provide the upstream receiver with enough information to extrapolate the characteristics of the minislot. In OFMDA channels with higher channel variability, a larger number of pilots are needed to derive the characteristics of the minislot.

DOCSIS 3.1 CMs are required to be capable of transmitting four defined US Pilot Patterns, numbered Pilot Patterns 1-4. Pattern 1 sends the fewest number of pilots and is lowest in overhead, and Pattern 4 sends the most pilots and is consequently most robust.

There are 7 US Pilot Patterns in total. [PHYv3.1] requires the CM to support all seven US Pilot Patterns and requires the CMTS to support US Pilot Patterns 1-4. In order for PMA to consider US Pilot Patterns 5-7 for use, PMA must query the CMTS for its capability.

In TaFDM where the same frequency band is shared between SC-QAM and OFDMA, the pilot pattern used for the minislot could switch between body minislot and edge minislot patterns. Replacing body minislots with edge

minislots will accommodate for the increased number of edges in the OFDMA channel, when SC-QAM transmissions are present within the OFDMA channel.

A potential goal for the PMA is to choose the appropriate pilot pattern per minislot to facilitate CM-CMTS synchronization and optimal CMTS decoding of minislots given the channel conditions such as interference and noise [PHYv3.1]. However, the rate at which a channel may change may be too fast for closed-loop control between the PMA and the CMTS, for the PMA to make pilot pattern decisions in which case the choice of pilot pattern could be left to the CMTS. A third option is the PMA provides pilot pattern recommendations which the CMTS uses and can override with its own choice of patterns when needed.

IV.3 Upstream Channel Estimation

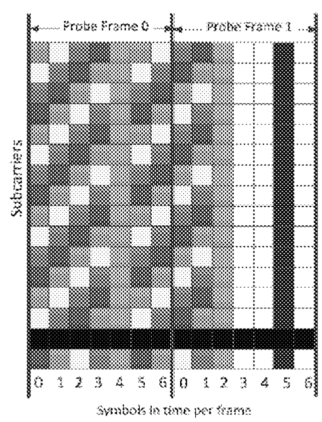
As in the downstream, the CMTS makes all decisions about profile assignments in the upstream. Unlike the downstream, the necessary measurements can be made at the upstream burst receiver within the CMTS, these include Codeword error statistics to check error rates and RxMER and other signal quality measurements to check margin. However, ways to tell the modem to transmit the desired measurement patterns/codewords at the right time is still needed. This includes Upstream Data Profile Testing Bursts to create test codewords and Probes for RxMER and other measurements.

IV.3.1 Probe

The goal with US probing is to have the PMA ask for statistics from the CMTS, and the CMTS in turn figures out how to get them (i.e., the CMTS decides the type and number of probes, etc.). The CMTS uses probes to calculate pre-equalization configuration and periodic transmission power and time-shift ranging. Probing is used during admission and steady state for pre-equalization configuration. Probing can also be used for periodic transmit power and timing adjustments. The Receiver can use probes to measure, Pre-equalizer coefficients, Received power, Timing offset, RX MER. A probe is BPSK PRBS sequence transmitted over all non-excluded subcarriers. The PMA could request for probing options such as pre-equalization, staggered, or interpolations(skip). Probe configurations options include Number of symbols, Measure RX MER ON/OFF, Transmission mode: Pre-equalization ON/OFF, Probe structure (full symbol/fixed/ staggered), and Transmission power (in case of MSM). Probes are sent during admission, normal operation or as per PNM server commands. Probes are sent periodically or on an as-needed basis e.g., UCD or profile change, performance degradation, timing offset increases etc.

IV.3.1.1 Probe transmission options

Allocations for probing are in symbols across subcarriers. Probes can have skip patterns where every N^{th} subcarrier is assigned and N is 1:8. Probe allocations are made on frame boundaries using a special type of bandwidth allocation, P-MAP (for Probe MAP). Probes can also have a staggered pattern that will be discussed with the P-MAP format. Probes transmission mode is controlled by the CMTS. All subcarriers in a symbol belong to the same CM. In staggered mode, CM shares symbols, each CM transmitting on a portion of the subcarrier.



SID	RSVD	Stagger	Probe Frame	Symbol In Frame	Start Subc	Subc Skip
Blue	0	1	0	0	0	3
Green	0	1	0	0	1	3
Yellow	0	1	0	0	2	3
Salmon	0	1	0	0	3	3
Med gray	0	0	0	4	0	0
Blue	0	1	0	5	0	3
Green	0	1	0	5	1	3
Yellow	0	1	0	5	2	3
Salmon	0	1	0	5	3	3
Purple	0	0	1	2	0	0
Red	0	0	1	5	0	0

Figure 22 - Sample Probe Frame and P-IEs

IV.3.1.2 Upstream Probes for RxMER Measurement

P-MAPs are used to command modems to transmit probes which the CMTS receiver can use to measure RxMER. Probe patterns transmitted by the modem are unchanged. A bit in the P-IE allows the CMTS to keep track of which probe grants it wants to use for measuring RxMER.

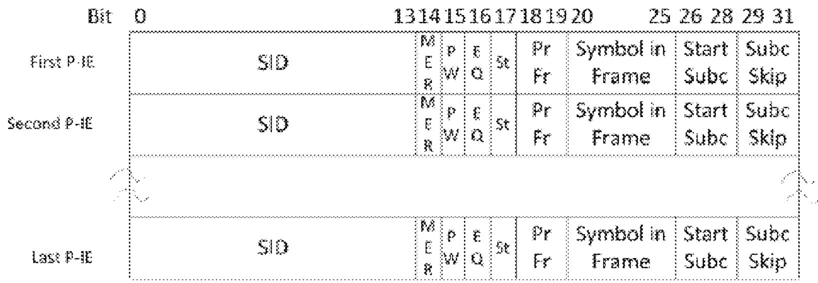


Figure 23 - Probe Information Element Structure

IV.3.2 Upstream Data Profile Testing Bursts

If the CMTS wants a CM to be able to transmit Upstream Data Profile Testing Bursts, it first assigns a special SID for this purpose, "OFDMA Upstream Data Profile (OUDP) Testing SID". The IUC of the profile to be tested must also be assigned to the CM ("Assigned OUDP IUC" sub-TLV of TCC). When the CM receives a valid grant to an OUDP Testing SID, it fills the grant with a specific pattern described in the [PHYv3.1]. The CM never sends "live" traffic on an OUDP Testing SID.

IV.3.3 Upstream Data Profile Testing Burst Content

Upstream Data Profile Testing bursts contain valid DOCSIS frames on which HCS and CRC may be checked. This provides additional error checking to supplement FEC statistics, which are based LDPC syndrome checks. CRC checking is not needed when testing downstream profiles since downstream error checking is provided by the BCH outer code.

The format and content of burst are detailed in [MULPIv3.1]. This includes Valid CCF "flow" with segment headers and valid pointers, no piggyback requests, a 6-byte DOCSIS headers with no EHDRs, a 64-byte packet PDU consists of valid Ethernet frame with valid CRC, DA = CMTS, SA = CM (same as MMMs), T/L = length and finally a counting pattern inside Ethernet PDU (0x01 to 0x2E).

IV.4 Initial Use of US Profile Management

The first step is to determine the upstream link characteristics separately for each modem. The following is a suggested process. Using US BW above 42 MHz, start with zero-bit loading, then use probes to increase bit loading.

Utilize the "test" profile in each modem to perform the following during times of a lightly loaded channel (no outstanding BW requests). The modem would send probe symbols, while the CCAP would receive, analyze, and iterate. The PMA/CMTS would measure, the Per-minislot (400 kHz spectrum band) estimated MER first (used to start bit loading iteration). The PMA would then iterate the bit loading per minislot to determine thresholds for the first occurrence of corrected codewords and uncorrectable codewords. If per-minislot error performance is too difficult or onerous, a group of minislots could be configured such that they have no errors; then one of the minislots would be modified to use a more aggressive bit loading and/or pilot pattern. The minislot group error performance could then be assumed to be caused by the modifications. Once thresholds are determined, the data would be recorded by the CMTS on a per modem / per minislot / per CCAP port (upstream service group) basis.

The PMA would then execute an algorithm to construct up to seven profiles with the goal being to maximize overall link capacity. There are two aspects to this complex task, parameters of each profile (bit loading and pilot patterns) and the assignment of each modem to a profile group.

These profiles are not necessary "higher" or "lower" in a speed/capacity hierarchy. Two profiles may have very similar capacities but very different minislot characteristics. For instance, group delay and amplitude response and intermodulation distortion can vary significantly between different modem locations in the field. For this reason, it is suggested that such a hierarchy for at least one low-capacity "shared" profile and perhaps also a "maintenance" profile is created. This "shared" profile would use bit loadings and pilot patterns for each minislot such that every properly functioning modem can successfully transmit error-free symbols. When a modem using a more aggressive profile experiences a (configurable) percentage of uncorrectable codewords received by the CCAP, the modem can be quickly assigned to the shared profile while waiting for a new training sequence to be executed. A "maintenance" profile could be created for modems that do not meet basic throughput requirements, but are able to communicate at a reduced speed. This would help in cases where the upstream link is impaired in a portion of a service group, and the reduced speed may be adequate for basic telephony and set-top applications.

IV.5 Additional Diagnostic Information in UEPI

The upstream burst receiver in the CMTS delivers upstream bursts and accompanying status information to the CMTS MAC for further processing. The Remote PHY UEPI specification [R-UEPI] defines a standard interface in the form of a set of UEPI pseudowires between the RPD, which contains the US burst receiver, and the CCAP Core which accommodates the DOCSIS MAC. While UEPI document was developed specifically for R-PHY architecture, it is believed that identical or largely similar interfaces are used in majority of integrated CMTS implementations.

UEPI pseudowire formats define additional diagnostic information elements that are available to the CMTS, beyond what is listed above in this section. See R-UEPI specification [R-UEPI]. The diagnostic information is carried in UEPI trailer and includes power evaluation of received data burst (high, low energy), information about the number of performed LDPC iterations for codewords in the burst, number of codewords that failed pre-decoding syndrome check, but passed post-decoding syndrome check in this burst, burst MER and other vendor specific information.

There are currently no requirements defined for the CMTS to maintain this information nor standard interfaces to expose this information on the CMTS. Methods to expose this information will be an area of future study.

Appendix V CM Based Data Collection

V.1 Selection of an OFDM Channel

V.1.1 Obtain List of OFDM channels

IF-MIB::ifIndex.79 = INTEGER: 79

IF-MIB::ifType.79 = INTEGER: docsOfdmDownstream (277)

IF-MIB Object ID	Type	Access	Value
ifIndex.< ofdmIndex >	Integer	R/O	Index of Interface
ifType,< ofdmIndex >	Integer	R/O	docsOfdmDownstream (277)

V.1.2 Determine OFDM PLC Center Frequency

The band index 0, of this attribute provides DOCSIS 3.1 PLC 6MHz Center Frequency.

DOCS-IF31-MIB::docsIf31CmDsOfdmChannelPowerCenterFrequency.79.0 = Gauge32: 835000000

DOCS-IF31-MIB Object ID	Type	Access	Value
docsIf31CmDsOfdmChannelPowerCenterFrequency.<ofdmIndex>.0	Gauge32	R/O	PLC Center Frequency(Hz)

V.2 PNM Bulk Operation

V.2.1 DocsPnmBulkDestIpAddrType

This object represents the IP address type of the 'docsPnmBulkDestIpAddr' object. A successful connection depends on the value of this attribute being set to an IP Family supported by the device. For example, if this value is set to IPv6 and the device is operating in an IPv4-only mode, a successful upload will not be possible.

V.2.2 DocsPnmBulkDestIpAddr

This object represents the IP address of the server to which the bulk data file is to be sent.

V.2.3 DocsPnmBulkDestPath

This object represents the path, excluding the filename, at the server to which the captured data file is to be sent. The CM cannot allow the value of docsPnmBulkDestPath to change if the value of PnmCmCtlStatus is any value other than 'ready'.

V.2.4 DocsPnmBulkUploadControl

This attribute controls the action taken by the device when a new bulk data file is generated.

DOCS-PNM-MIB::docsPnmBulkDestIpAddrType.0 = INTEGER: 1

DOCS-PNM-MIB::docsPnmBulkDestIpAddr.0 = Hex-STRING: 0A FC 25 72

DOCS-PNM-MIB::docsPnmBulkDestPath.0 = STRING:

DOCS-PNM-MIB::docsPnmBulkUploadControl.0 = INTEGER: 3

DOCS-PNM-MIB Object ID	Type	Access	Value	Require Attribute
docsPnmBulkDestIpAddrType.0	InetAddressType	R/W	IPv4 = 1 IPv6 = 2	Yes
docsPnmBulkDestIpAddr.0	InetAddress	R/W	Inet Hex Format	Yes
docsPnmBulkDestPath.0	SnmpAdminString	R/W	String	No
docsPnmBulkUploadControl.0	Integer	R/W	AutoUpload = 3	Yes

Inet Hex Format		
Protocol	**Inet Address**	**Hex Format**
IPv4	10.252.37.114	0A FC 25 72
IPv6	2001:558:ff2e:16:10:252:37:114	20 01 05 58 FF 2E 00 16 00 10 02 52 00 37 01 14

V.3 PNM CM Downstream OFDM Receive MER Operation

DOCS-PNM-MIB::docsPnmCmDsOfdmRxMerFileName.79 = STRING: DsOfdmRxMer_1456436343248

DOCS-PNM-MIB::docsPnmCmDsOfdmRxMerFileEnable.79 = INTEGER: 2

If an RxMER filename is not defined, the CM auto assigns a filename based on a well-known nomenclature.

Filename Nomenclature: PNMDsMer_<CM MAC address>_<epoch>

V.3.1 DocsPnmCmDsOfdmRxMerFileName

This attribute is the name of the file at the CM which is to be downloaded by the PNM server.

V.3.2 DocsPnmCmDsOfdmRxMerFileEnable

This attribute causes the CM to begin the RxMer measurement for creating a file of RxMer data. When the measurement is complete, the FileEnable attribute is set internally to 'false' by the CM.

PNM Bulk Object ID	Type	Value	Required Attribute
docsPnmCmDsOfdmRxMerFileName.<ofdmIndex>	SnmpAdminString	String	No but recommend to keep track
docsPnmCmDsOfdmRxMerFileEnable.<ofdmIndex>	TruthValue	True = 1 Start RxMer Measurement	Yes

V.4 RxMER Measurement Status

These below objects confirm the current test and operational status. When docsPnmCmCtlStatus returns a ready status, the CM is ready to conduct another test.

V.4.1 DocsPnmCmCtlTest

This attribute represents the current test. The value could represent the current test in-progress, or if no test is running, the last test that was attempted.

V.4.2 DocsPnmCmCtlStatus

This attribute represents the overall status of the PNM test platform. Individual tests within the PNM test suite have their own specific objects to start and stop.

DOCS-PNM-MIB::docsPnmCmCtlTest.0 = INTEGER: 2

DOCS-PNM-MIB::docsPnmCmCtlStatus.0 = INTEGER: 2

DOCS-PNM-MIB Control	Type	Access	Value
docsPnmCmCtlTest	Integer	R/O	dsOfdmRxMERPerSubCar(6)
docsPnmCmCtlStatus	Integer	R/O	ready(2) testInProgress(3) tempReject(4)

V.5 TFTP Transfer and PNM Bulk File Status

Upon completion of the test operation, the device attempts to upload the PNM Bulk file to the PNM server.

V.5.1 DocsPnmBulkFileUploadStatus

This attribute reflects the status of the bulk data file.

V.5.2 DocsPnmBulkFileName

This object contains the name of the bulk data file stored in the device that is available to be uploaded to the server.

If an RxMER filename is not defined, the CM auto assigns a filename based on a well-known nomenclature.

Filename Nomenclature: PNMDsMer_<CM MAC address>_<epoch>

DOCS-PNM-MIB::docsPnmBulkFileName.53 = STRING: DsOfdmRxMer_1456507759817

DOCS-PNM-MIB::docsPnmBulkFileControl.53 = INTEGER: 1

DOCS-PNM-MIB::docsPnmBulkFileUploadStatus.53 = INTEGER: 4

DOCS-PNM-MIB Object ID	Type	Access	Value
docsPnmBulkFileUploadStatus.<RowCreateIndex>	Integer	R/O	other(1), availableForUpload(2), uploadInProgress(3), uploadCompleted(4), uploadPending(5), uploadCancelled(6), error(7)
docsPnmBulkFileName.<RowCreateIndex>	SnmpAdminString	R/O	

V.6 SNMP Set and Query Sequence

The following is a sample SNMP sequence that will instruct the CM to perform an RxMER test and SNMP query sequence to determine the start and wait for the CM to conclude its test operation.

Before the start of this sequence, verify the CM Inet address type. This address type must match the address type of the TFTP Server.

SNMP Index Example

- DS OFDM Index = 79

- PNM Bulk File Index = 50

SNMP Set	
Set Object ID	**Value**
docsPnmBulkUploadControl.0	3
docsPnmBulkDestIpAddrType.0	2
docsPnmBulkDestIpAddr.0	20 01 05 58 FF 2E 00 16 00 10 02 52 00 37 01 14
docsPnmCmDsOfdmRxMerFileName.79	DsRxMER_1461887403823
docsPnmCmDsOfdmRxMerFileEnable.79	1

SNMP Query	
Query Object ID	**Response**
docsPnmCmCtlTest.0	dsOfdmRxMERPerSubCar(6)
docsPnmCmCtlStatus.0	ready(2) testInProgress(3)
docsPnmBulkFileName.50	DsRxMER_1461887403823
docsPnmBulkFileUploadStatus.50	uploadInProgress(3) uploadCompleted(4)

At this point, obtain PNM RxMER file for further processing.

Appendix VI Multicast Profile Handling

VI.1 DOCSIS 3.1 Multicast Profile Management

If the CMTS wants PMA to do the multicast profile management, the CMTS needs to notify the PMA when CM wants to join or leave a multicast group. Then, the PMA selects the LCD profile that should work for all CMs. After that, the PMA asks the CMTS to assign the profile to all CMs in the multicast group.

Figure 24 shows the interactions between the PMA and CMTS to use the LCD multicast profile when CM joins or leaves the multicast group.

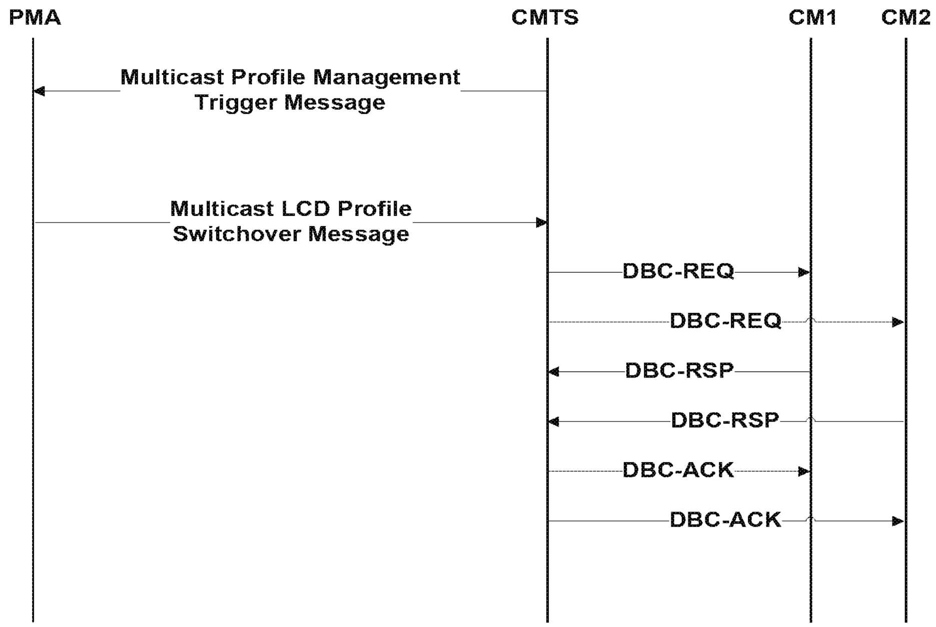


Figure 24 - Multicast Profile Optimization

The CM joins a multicast group when it receives the first join request for the multicast group from one of the clients connected to it. The CM leaves a multicast group when the last client connected to the CM leaves the multicast group.

Further optimizations can be performed by the PMA to allow more than one multicast profile for a given multicast group. However, these optimizations will be addressed in a future revision of this Technical Report.

VI.2 Multicast Profile Management Application Interface

When one or more CM Join/Leave multicast group, the CMTS sends a message to PMA. This message has the following elements:

1) Downstream Channel ID,
2) Multicast Group ID,
3) Indicator, for whether the CM joins or leaves the multicast group,
4) List of MAC address of CM(s) that have joined/left the Multicast group.

Appendix VII Acknowledgements

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